SCHOOL OF

CIVIL ENGINEERING

INDIANA

DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-95/10

Final Report

USING PYROLIZED CARBON BLACK FROM WASTE TIRES IN ASPHALT PAVEMENT (Part I: Limestone Aggregate)

Taesoon Park and C. W. Lovell

PURDUE UNIVERSITY

FINAL REPORT

USING PYROLIZED CARBON BLACK FROM WASTE TIRES IN ASPHALT PAVEMENT
(Part I, Limestone Aggregate)

by

Taesoon Park
Graduate Research Assistant

and

C.W. Lovell
Research Engineer
Purdue University
Department of Civil Engineering

Joint Highway Research Project

Project No.: C-36-55L
File No.: 2-12-13

Prepared in cooperation with the
U.S. Department of Transportation Federal Highway Administration

Purdue University
West Lafayette, IN 47907
February 20, 1996

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-95/10		

4. Title and Subtitle	5. Report Date
Using Pyrolized Carbon Black (PCB) from Waste Tires in Asphalt Pavements (Part I, Limestone Aggregate)	February 20, 1996
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
Taesoon Park and C. W. Lovell	FHWA/IN/JHRP-95/10
9. Performing Organization Name and Address	**10. Work Unit No.**
Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	**11. Contract or Grant No.**
12. Sponsoring Agency Name and Address	**13. Type of Report and Period Covered**
Indiana Department of Transportation Indiana Government Center North 100 North Senate Avenue Indianapolis, IN 46204	Final Report September, 1993 to May, 1995
	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

This study presents the viability of using PCB as an additive in hot mix asphalt concrete. Different ratios of PCB (5%, 10%, 15%, 20% by weight of asphalt) were blended with two grades of asphalt (AC-10 and AC-20). The complete behaviors of the PCB modified asphalt concrete were investigated by comprehensive laboratory testing and evaluation. The Marshall method was used to determine the optimum binder content, and the mechanical properties and void relationships were investigated by this method. The Gyratory Testing Machine was used to define the stress-strain relationships of the PCB mixtures. The rutting potential of PCB mixtures was investigated using the Dynamic Creep Testing. The performance of the PCB mixtures at low temperature (5°C) was determined by the Indirect Tensile Testing. The strength performance of the PCB mixtures at intermediate temperatures (5°C and 25°C) was examined by the Resilient Modulus Test. The Hamburg Wheel Tracking Device was employed to ascertain the stripping potential of the PCB mixtures.

The findings of this study show beneficial effects of added PCB for asphalt mixture. Specifically, test results show that PCB contents of 10% to 15% by weight of asphalt produce a number of significant improvements. The rutting potential, the temperature susceptibility and the stripping potential can be reduced by the inclusion of PCB in the asphalt mixture. Added material costs of about 6% may well be justified by expected improvements in performance.

17. Key Words	18. Distribution Statement
Pyrolized carbon black, carbon black, addititives, hot mix asphalt, asphalt concrete, rutting, stripping, resilient modulus, cracking	No restrictions. This document is available to the public through the National Technical Information Service, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	314	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The authors appreciate the efforts of a number of people who helped this project successfully. First, we would like to express our gratitude to the Study Advisory Committee (SAC) members, Mr. Hoffman, Mr. Walker, Mr. Ward, Ms. McDaniel, Dr. Salgado, Mr. Terrell and Dr. King.

The work was largely performed in the facilities of the Division of Research, Indiana Department of Transportation in West Lafayette, Indiana. We especially extend thanks to Ms. McDaniel, Dr. Coree and Mr. Lovvorn in the Division of Research. The National Center for Asphalt Technology (NCAT) in Auburn, Alabama and the Koch Materials office in Terre Haute, Indiana were cooperative and helpful in providing the creep testing equipment and Hamburg wheel tracking device. Special thanks extended to Dr. Brown and Mr. Royer at NCAT, Dr. King and Mr. Thomas at Koch materials.

We also would like to thank Ms. Janet Lovell at Purdue University, who supervised the geotechnical laboratories.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ASTM :	American Society for Testing and Materials
ATS :	Automated Testing Systems
CB :	Carbon Black
CRA :	Crumb Rubber Additive
DBP :	Dibutyl Phthalate
DOT :	Department of Transportation
EPA :	Environmental Protection Agency
Eg :	Gyratory Compression Modulus
GCI :	Gyratory Compactibility Index
Gg :	Gyratory Shear Modulus
GSF :	Gyratory Shear Factor
GSI :	Gyratory Stability Index
GTM :	Gyratory Testing Machine
HAF :	High Abrasion Furnace
HMA :	Hot Mix Asphalt
INDOT :	Indiana Department of Transportation
LVDT :	Linear Variable Differential Transducer

MTS :	Material Testing Systems
NAPA :	National Asphalt Pavement Associations
OECD :	Organization for Economic Cooperation and Development
PCB :	Pyrolized Carbon Black
SAM :	Stress Absorbing Membranes
SAMI :	Stress Absorbing Membrane Interlayers
Sg :	Gyratory Shear
SHRP :	Strategic Highway Research Program
VFA :	Voids Filled by Asphalt
VMA :	Voids in Mineral Aggregates
VTM :	Voids in Total Mix

IMPLEMENTATION REPORT

The main objective of this research is to evaluate the viability of using Pyrolized Carbon Black (PCB) from waste tires as a reinforcing agent in asphalt mixtures. It has been previously reported that commercial carbon black modified asphalt increased the rutting resistance at high temperature and the durability of asphalt concrete. It has been shown that the temperature susceptibility and the cracking propagation potential of asphalt at low temperature has been decreased by such modification. It was believed that PCB could produce similar benefits, and this laboratory study has shown that such is the case.

Conventional mix design methods, such as the Marshall method, can be used to determinate the optimum binder content for the PCB modified asphalt. Major problems of asphalt mixture were found to be reduced with the inclusion of PCB. The inclusion of PCB in both AC-10 and AC-20 grades of asphalt improved the shear resistance. The resilient modulus increased with the inclusion of PCB in both AC-10 and AC-20 mixtures. The plastic deformations, rutting potential decreased with added PCB in AC-10 mixtures. Also, the temperature susceptibility of PCB modified asphalt decreased. The stripping potential was decreased with the use of PCB in both grades of asphalt. The added material cost for the PCB is about 6 % of the total cost, and improvements in performance may well justify such increases.

Based on the laboratory test results, mixing technology of PCB in asphalt should be studied in the laboratory prior to further attempts in the field. A field study is recommended to verify the benefits of PCB, which were observed from the laboratory

The existing studies of (a) PCB modified binder characteristics and (b) PCB modified asphalt concrete parameters when slag aggregates are used should be completed.

In addition, there should be a review of best procedures for mixing PCB with asphalt for field applications. This should all be completed in early 1996. Assuming that these other components of this study are as positive as this one, a test road should be planned for 1996. The test road would provide very substantial evidence that the improvements observed in the laboratory are indeed real, and that theses improvements justify the increased PCB costs. Mixes for the test road will be provided from the laboratory studies.

CHAPTER 1

INTRODUCTION

1.1 Background of Research

It is estimated that over 242 million waste tires are generated each year in the United States. In addition, it is reported that approximately 2 billion waste tires are accumulated in stockpiles or uncontrolled tire dumps across the country (EPA, 1991). Therefore, an effective and economical strategy is needed to handle the waste tire problem. Pyrolysis of scrap tires, a rapidly developing and spreading technology, is an effective and economical strategy to process waste tires. As many as 5000 waste tires per day can be processed by tire pyrolysis in a single factory (Wolf Industries, 1994, Cindy et al., 1990).

Carbon black and oil are the main byproducts of the pyrolysis of scrap tires which typically yields 55 % oil, 25 % carbon black 9 % steel, 5 % fiber and 6 % gas. The carbon black derived from the tire pyrolysis is called pyrolized carbon black (PCB) in this study to distinguish it from the commercial carbon black (CB). The pyrolized carbon black typically contains 75 % carbon black, a maximum of 9 % ash, 4 % sulfur, and 12 % of minimum butadiene copolymer (Roy et al., 1990).

Commercial carbon black is an intensely black, fine powdery substance that has been used as a basic raw material for rubber, printing ink, electrical wires and plastic products. Over two-thirds of the carbon black is used as a reinforcing agent by the tire industry. According to Rostler et al. (1977), until 1919, most of the automobile tires were white or red and lasted only 5,000 miles. However, due to the use of CB in the tire industry, practically all tires were black and lasted 15,000 miles to 20,000 miles by 1929. Today, tires may last far beyond 20,000 miles.

The use of carbon black as a reinforcing agent for hot mixed asphalt may produce a similar benefit. It has been proposed that CB also be used to reinforce the asphalt cement in pavements (Rostler et al, 1977). Yao and Monismith (1986) and Vallerga and Gridley (1980) reported that the use of CB increased the rutting resistance at high temperature and the durability of asphalt. They also found that the temperature susceptibility and the cracking propagation potential of asphalt at low temperature decreased. In spite of its effectiveness as a modifier, however, use of CB has been somewhat limited due to its relatively high material cost.

This study proposes to use PCB in lieu of CB as a reinforcing agent for conventional asphalt concrete. Pyrolized carbon black has a relatively high CB content and may reasonably be expected to enhance the performance of asphalt pavement. Pyrolized carbon black is obtainable as a byproduct of tire pyrolysis and is a relatively inexpensive raw material. Furthermore, tire pyrolysis could be a remedy for the mass disposal problem of scrap tires. Below, the objectives of research, the method used for research, and a description of the chapters in this formal report are described.

1.2 Objectives of Research

This study has two main objectives: a) to investigate the viability of using PCB as an additive in hot mix asphalt pavement; b) to demonstrate the degree of improvement achieved by use of the additive.

1.3 Method of Research

In the present study, the following laboratory tests were carried out to evaluate the performance and the characteristics of the PCB modified asphalt. The laboratory tests include the Marshall method, Gyratory Testing Machine (GTM), Dynamic Creep Test (confined), Resilient Modulus Test, Indirect Tensile Test and Hamburg Wheel Tracking Device.

The Marshall method was used to determine the optimum binder content. This method was also used to evaluate the characteristics of each mixture in terms of Marshall stability and flow, air-voids, voids in mineral aggregates (VMA), and voids filled by asphalt (VFA). The optimum binder content was used to produce test specimens.

The Gyratory Testing Machine (GTM) was used to investigate the stress and strain relationship of the mixtures. The Gyratory Compactibility Index (GCI), Gyratory Stability Index (GSI), Gyratory Shear (Sg), and variation of unit weight were then evaluated and compared.

The Dynamic Creep Test (confined) was carried out to investigate the rutting potential of each mixture. The results were evaluated in terms of mix stiffness, creep compliance and corrected cumulative creep.

The Resilient Modulus Test was performed to evaluate the temperature susceptibility and the strength, and the cracking potential for each mixture was obtained from the Indirect Tensile Test. The Hamburg Wheel Tracking Device was employed to determine the moisture susceptibility and the rutting potential of the mixtures.

Different ratios of PCB (5 %, 10 %, 15 %, 20 % by weight of the asphalt) were blended with two different grades of asphalt (AC-10 and AC-20). The test results were compared to the CB modified asphalt mixtures (5 %, 10 %, 15 %, 20 % by weight of the asphalt) and the conventional AC-10 and AC-20 mixtures.

1.4 Format of Report

This report consists of seven chapters that present a review of literature, describe the research conducted, state the conclusions, and offer recommendations. The appendices to this report present the test results obtained in the course of research. The following is a brief description of the chapters in this study.

Chapter 2 provides a summary of the current technologies that exist for scrap tire disposal. This chapter also describes the application of scrap tires in the fields of geotechnical engineering, pavement materials, and highway construction. Chapter 3 provides a review of the current literature on the use of commercial carbon black in the field of asphalt pavement. Chapter 4 describes the properties of the materials used in this study. The materials include the aggregate, pyrolized carbon black, commercial carbon black, and two grades of asphalt (AC-10 and AC-20). Chapter 5 explains the test methods and protocols, the preparation of specimens and the equipment used in each test. Chapter

6 presents analyses of the data obtained and discussions about these test results. Comparisons are made between test results, and cost data are supplied. Chapter 7 contains the conclusions reached in this study and offers recommendations for further research.. The appendices contain the results for the Marshall method, Gyratory testing machine, Dynamic creep test, Resilient modulus, and Hamburg wheel tracking device.

CHAPTER 2.

DISPOSAL AND APPLICATION TECHNOLOGY FOR SCRAP TIRES

2.1 Introduction

Various concepts and techniques are proposed and developed for efficient and economical utilization of scrap tires. Highway construction and asphalt pavements have led to the most popular efforts for this purpose. Recycling of scrap tires is highly desirable and a leading activity for environmental protection.

The objectives of this chapter are to introduce and to review the current recycling, disposal technology and application of scrap tires in the fields of geotechnical engineering, asphalt pavement materials and highway design.

2.2 Disposal Technology

2.2.1 Source Reduction

According to the EPA (1991), reduction of the number of tires used is needed to minimize the tire disposal problem. Three applications, 1) design of longer wearing tires, 2) reuse of used tires, and 3) retreading can be considered. The first two have been used by manufacturers and consumers. Retreading involves the application of a new tread to a worn tire that still has a good casing. It is known that retreading of worn tires is an efficient, viable procedure for scrap tire recycling.

2.2.2 Incineration

Incineration of scrap tires has a longer history than other disposal methods because of its simplicity. However, incineration may produce environmental problems due to the air emissions from the burning process. If the environmental problem is controlled adequately, this method may be the best for mass disposal of scrap tires. Scrap tires are an excellent fuel source, with an estimated heating value ranging from 12,000 to 16,000 Btu/lb (EPA, 1991), compared to coal and municipal waste fuel values of 12,000 to 12,600 Btu/lb and 2,500 to 8,500 Btu/lb, respectively (Beckman, 1974).

According to Ahmed and Lovell (1992), proven technology exists to efficiently burn whole, shredded, or granulated tires, while meeting all applicable pollution control codes. In 1990, 10 percent of the total scrap tires generated, about 25.9 million tires, were burned for energy production. The use of tires and tire-derived fuel (tdf) can be accomplished in various combustion facilities such as power plants, tire manufacturing plants, cement klins, pulp and paper plants and small package steam generators (EPA, 1991)

2.2.3 Pyrolysis

Pyrolysis of scrap tires is a rapidly developing and spreading technology. Pyrolysis is a method of decomposing tires by a cooking process in order to break down the rubber into salable by-products. Tire pyrolysis yields approximately 55 % oil, 25 % carbon black, 9 % steel, 5 % fiber and 6 % gas (Roy et al., 1990). The yield can be varied depending on the operation conditions such as temperature and pressure. High temperature (i.e., 900°C), pyrolysis yields larger quantities of residues, which are called pyrolized carbon

black in this study, steel and ashes. Lower temperature pyrolysis yields larger quantities of oils, mostly olefins, aromatics, and naphtenes (OECD, 1981)

Destructive distillation and carbon black recovery are the two main operations in the pyrolysis of tires. As many as 5000 waste tires can be processed in a day by a single facility (Cindy et al., 1990). The products recovered in pyrolysis can be reprocessed for the manufacturing industry and for the construction industry. In order to be an effective and economical method (Roy et al., 1990), 1) whole tires should be used as feedstock rather than shredded tires; 2) the plant operation should be supported by a high-quality control laboratory that can be operated by low-level technicians. In addition, it is necessary that constant and steady markets exists for the carbon black and other residues, which otherwise need to be landfilled.

2.3 Application Technology

Tires may be used in total or in parts. Sidewalls and treads may be cut from the whole and linked in various ways to constitute mats. The entire tire may also be cut or shredded and the parts used in various ways.

2.3.1 Geomaterial and Geotechnical Applications

Soil Reinforcement and Retaining

Soil can be reinforced with whole scrap tires. Various agencies, in the United States and abroad, have tested and evaluated the use of whole tires for soil reinforcement and retaining. The use of whole tires or sidewalls and treads in embankment construction

was reported by Forsyth and Egan (1976). The sidewalls and treads can be separated into mats and strips which are used to increase stability in soil embankments.

The product Terramat was developed and patented by Construction Incorporated, Youngstown, Ohio (Biocycle, 1989). Tire sidewall mats are linked with stainless steel strapping to provide a temporary road across a swampy area. The Terramat system is economical in soft, unstable and waterlogged areas.

Pneusol (Rubbersoil) has been developed (1976) in France (Ahmed, 1993). It is a combination of soil and tire parts, which may be linked in chains or placed in layers. The study showed that Pneusol improves the mechanical properties of soil either anisotropically or isotropically (Audeoud et al., 1990).

According to Caltrans (1988), whole tires anchored into the backfill are used in various configurations to retain heights of soil up to 10 feet. This technique is mostly used in California to prevent slope failure along local highways.

Erosion Control and Offshore Protection

The California Transportation Research Division used discarded tires to mitigate several erosion problems. Tires bound together and partially or completely buried on unstable slopes were tested between 1982 and 1986. California found that this application was practical and economical.

Scrap tires also have been used for shoreline protection. Breakwaters to protect the harbor and shorelines against full transmission of wave energy are an example. According the to EPA (1991), the US Army Corps of Engineers found that scrap tire

breakwaters were effective for smaller waves and had excellent energy absorbing properties.

The US Bureau of Sport Fisheries and Wildlife has been experimenting with artificial reefs made from used tires since 1965. The artificial reefs provide shelters for aquatic life (Ruth, 1991). This technique is preferred due to its low cost of material (tires), longer service life, large surface area, ease of design and construction, and especially, as a convenient method for mass disposal. However, construction of artificial reefs is labor intensive and thus expensive. Also, the long term effect of artificial reefs on the ocean environment is yet unknown.

Lightweight Fill

Lightweight fills lessen settlement and increase stability over soft foundations. Woodchips or sawdust generally have been used, however, wood is biodegradable and thus lacks durability. Shredded tires can be used for this purpose, because tires are non-biodegradable. Various methods have been attempted, i.e., tire chips mixed with different contents and types of soil or tire chips layered with soils. Ahmed (1993) and Ahmed and Lovell (1992) present excellent discussions of rubber soil and use of tire chips in highway construction.

Synthetic turf, playground gravel substitutes and mulch are other good examples of the use of shredded tires. Tire tuft is prepared by mixing shredded tires (bead-free) with binder, such as polyurethane, latex, or asphalt. The tire turf is laid like concrete and cures overnight (Anderson, 1972). In commercial playgrounds, gravel substitutes and running tracks are composed of tires shredded to sizes ranging from 1/4 in. to 5/8 in. Steel is

removed from the tire chips to provide a better cushion, and a more durable, cleaner environment than conventional gravel, stones and wood. Shredded tires may also serve as a mulch for landscaping along highways. Wood chips and straw have also been used as mulch. The advantages of tire chips for mulch are durability and ease of maintenance.

2.3.2 Asphalt Pavement and Highway Applications

Crumb rubber is produced by either cryogenics or mechanical size reduction with shredders and grinders (EPA, 1991). In the cryogenic process, the cooled tire pieces drop into a hammer mill to be fractured into crumb rubber, steel, and fiber. In the mechanical process, tires are shredded to 3/4 inch chips, and then a magnetic and fiber separator removes all steel and polyester fragments. The rubber chips are then further reduced to pebbles by a cracker grinder. A series of screening and regrinding operations achieves the desirable crumb size of 600 to 800 microns.

Crumb rubber has been utilized for rubber and plastic products or processed into reclaimed rubber or asphalt products. When crumb rubber is used in asphalt paving products, it is called crumb rubber additive (CRA). Two incorporation processes are available, one is a wet process where CRA is blended with asphalt cement, and the other is a dry process where CRA is mixed with hot aggregate.

<u>Crack/Joint Sealant</u>

Crack/joint sealant is one of the asphalt-rubber applications. An amount of 15 percent to 30 percent CRA is blended with asphalt cement, and this product is used by many state highway agencies. The performance is found to be generally satisfactory,

although use of CRA increases cost. However, the additional cost may be justified in view of better performance and longer service life of the sealant

Surface/Interlayer Treatments

Stress absorbing membranes (SAM) and stress absorbing membrane interlayers (SAMI) are used for surface/interlayer treatment applications. The CRA is used to manufacture SAM and SAMI. The implementation of SAM is not only to seal underlying cracks and prevent the entry of surface water into the pavement structure, but also to absorb the stresses that would allow the underlying cracks to reflect up to the surface. The difference between SAM and SAMI is that SAM does not have an overlay, whereas SAMI does (Ahmed, 1991). Both SAM and SAMI increase the cost. Heitzman (1992) reported that this additional cost in SAM and SAMI may be justified due to their somewhat better performance and generally longer service life.

Asphalt-Rubber Binder and Mixtures

Charles McDonald developed a highly elastic maintenance surface patching by using CRA. An amount of 15 to 20 percent CRA by weight of asphalt cement was used in asphalt-rubber binder production to be known as the McDonald technology (Heitzman, 1992). According to McQuillen and Hicks (1987), the advantages of using asphalt-rubber in hot mix asphalt include a higher viscosity than conventional asphalt at 140°F (60°C), tougher and more elastic surface, and greater resistance to aging. This technology is patented by the Sahuaro Petroleum Asphalt Company and the Arizona Refinery Company.

Rubber Modified Asphalt

Rubber modified asphalt is a dry process. This concept was developed in the late 1960s in Sweden and then introduced in the United States in the 1970s as the patented product called PlusRide (Allen and Turgen, 1990). According to Takallou and Hicks (1988), 3 percent by weight of coarse and fine rubber particles are used to replace the aggregates in the PlusRide process. PlusRide has a unique mix design procedure. Only the quantity of air voids is determined to establish the mix quality of asphalt. The two most significant advantages are decrease of reflection and thermal cracking and increase of skid resistance (McQuillen and Hicks,1987). Many studies indicated that the performance and characteristics of the mixture are improved and the service life of pavement extended by including CRA as a binder or as an aggregate substitute. However, the questionnaire survey performed by Ahmed (1991) showed that the advantages are not always verified, especially in field performance. Therefore, more research is required to substantiate the use of CRA for rubber modified asphalt.

CHAPTER 3

USE OF COMMERCIAL CARBON BLACK IN ASPHALT MIXTURES

3.1 Background

The use of carbon black as an additive in asphalt pavement mixtures to enhance the performance has been investigated by many researchers. The use of carbon black is intended to improve rutting resistance, reduce temperature susceptibility, and decrease low temperature cracking.

The concept of using carbon black as an reinforcing agent for asphalt was first introduced by Alliotti (1962), who described the characteristics of carbon black and identified its potential advantages as an asphalt additive.

3.2 Summary of Laboratory Studies

Martin (1962) performed laboratory testing with pelletized rubber grade carbon blacks. Martin's test results did not show any improvement of the performance of asphalt because of poor dispersion, low carbon black concentrations, and the incompatibility of fluxing oil added to the carbon black.

In 1977, Rostler et al. (1977) reported fundamental differences between carbon black modified asphalt and conventional asphalt. They described the usefulness and effectiveness of carbon black in asphalt pavement. A pelletized carbon black product was developed for asphalt pavement mix design as a result of the study. They found the 75 %

carbon black and 25% fluxing oil ratio to be a good compromise for practical applications. Pelletizing with oil aids handling loose carbon black in the field and also provides proper dispersing effects in asphalt. The test results showed that the inclusion of 10 to 15 percent carbon black by binder weight could substantially improve the properties of asphalt, including reduction of temperature susceptibility and age hardening. Also they found that among the many types of carbon black, the high structure high abrasion furnace (HAF) type of carbon black is the most useful for asphalt cement reinforcement.

Vallergra and Gridley (1980) indicated the importance of proper dispersal of carbon black particles in asphalt to achieve the desired effects. They also recommended the use of a pelletized carbon black for adequate dispersing action. The good dispersal action ensures the microfiller effect in asphalt binder so that the usefulness of carbon black can be maximized. The field observation and laboratory test results revealed that durability, wear resistance, and temperature-viscosity susceptibility were improved by the use of submicrometer-size carbon black at contents of 11 to 16 % by weight of asphalt. The strength determined by the Marshall load test was increased 40 %. Reduced wear was observed in the carbon black section compared to the conventional asphalt section. The increase of the stiffness of the asphalt at high temperature did not affect its low temperature stiffness characteristics. They confirmed the usefulness of high structure HAF type carbon black as a reinforcing agent in an asphalt mix. They also found that the properties of a given asphalt carbon black blend varied somewhat depending on the characteristics of the asphalt.

Yao and Monismith (1986) found that, with 15 to 20 percent Microfil 8 (carbon black) in the mixture, there was improvement of rutting resistance at high temperatures. The results of unconfined creep tests showed that carbon black mixtures exhibited less change in creep modulus with time than conventional mixtures. While not improving the fatigue and tensile characteristics of the mixtures, carbon black did not adversely affect them either. They concluded that a comparatively soft asphalt may be used to mitigate low temperature cracking and yet provide improved resistance to rutting when treated with carbon black.

Most recently, Khosla(1991) carried out a study of various additives including carbon black. He found that carbon black modified asphalt reduced temperature susceptibility, increased resilient modulus values at higher temperatures, and increased rutting resistance compared to conventional asphalt.

The previous studies acknowledged the usefulness of carbon black as a reinforcing agent. Three common features of thses studies are that: 1) the commercial pelletized carbon black (Microfil 8) was used for the mix design; 2) the effective ratio of carbon black ranges between 10 % and 20 % by weight of asphalt; 3) the increase in rutting resistance is the most significant of all other improvements, however, the properties of carbon black modified asphalt are somewhat dependent on the characteristics of the asphalt used. A detailed summary of the test procedures, protocol and results are provided in Appendix A.

3.3 Summary of Field Studies

Field studies performed by several state DOTs produced varied results. Augeri (1986) of Connecticut reported incidents of eye and skin irritation. Therefore, protective equipment and clothing are recommended. Raven (1987) of Minnesota reported that carbon black with sulphur additive minimized flushing. The additional cost of carbon black and its processing in pavement construction seems to increase the construction cost. Hare (1990) from the Pennsylvania DOT does not recommend the use of carbon black because the benefits do not offset the additional cost. Foster (1990) of the Maine DOT reported no distinguishable improvement in the performance of the pavement. Lohrey (1991) of Connecticut showed that an addition of 15 percent carbon black by weight of binder reduced crack propagation, however, the cost of the project increased up to 47 percent.

As discussed above, field studies showed different results when they are compared to the laboratory test results. The possible reasons for these differences may include: different working conditions, weather, skill of the crew, etc.. It is reported that construction costs increased 40 % to 60 %, however, when the life of the pavement is considered, the construction cost would be offset by the improvement of the pavement performance. This is a rather typical problem in asphalt pavement studies, therefore, field studies are required to verify laboratory test results after the laboratory tests are completed. Two field studies performed by Connecticut DOT and Maine DOT are summarized in Appendix A.

CHAPTER 4

MATERIALS USED

4.1 Aggregate

A typical Indiana Dephi limestone was used for the mix design. The aggregates were obtained from local asphalt plant stock-piles. A vibrating table sieve shaker (Gilson Model 323333) was used to sieve the aggregate retained on the #4 (4.75 mm), and 8 inch diameter sieves used for the #8 (2.36 mm) aggregate to #200 (0.075 mm) aggregate. The Indiana Department of Transportation (INDOT) specification for #9 binder aggregate was adopted for the target gradation and the gradation of the aggregate was carefully controlled after an initial round of Marshall tests. The target gradation of the aggregate is shown in Figure 4.1. The fine aggregate was prepared by crushing the coarse fraction. Table 4.1 summarizes the gradation of the aggregate used for all the mix designs.

The bulk specific gravity and apparent specific gravity of the coarse aggregate are 2.47 and 2.51, respectively, and for the fine aggregate, they are 2.742 and 2.797, respectively. The bulk specific gravity and the apparent specific gravity of fine aggregate are 2.742 and 2.797, respectively. The absorption of coarse aggregate was 0.58, and was 0.71 for fine aggregate. For the coarse aggregate, the specific gravity testing was carried out in accordance with ASTM C127, and for the fine aggregate, in accordance with ASTM C128.

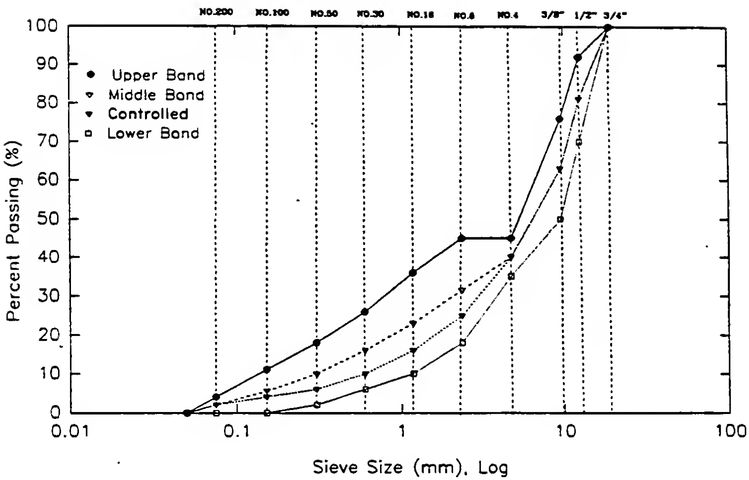


Figure 4.1 The Gradation of the Aggregate

Both tests were run three times by different operators and the results were averaged. The test results of specific gravity are summarized in Table 4.2.

Table 4.1 The Gradation of the Aggregate.

Sieve Size	% Passing (Controlled)	Spec. Range % Passing
3/4 " (19 mm)	100	100
1/2 " (12.5 mm)	81	70 - 92
3/8 " (9.5 mm)	63	50 - 76
# 4 (4.75 mm)	40	40 ± 5
# 8 (2.36 mm)	25	18 - 45
# 16 (1.18 mm)	16	10 - 36
# 30 (0.6 mm)	10	6 - 26
# 50 (0.3 mm)	6	2 - 18
# 100 (0.15 mm)	4	0 - 11
# 200 (0.075 mm)	2	0 - 4

Table 4.2 Summary of Specific Gravities.

Specific Gravity	+ No.4 Aggregate	- No.4 Aggregate
Bulk, Gsb	2.47	2.742
Apparent, Gsa	2.51	2.797
Absorption, %	0.58	0.71

4.2 Asphalt

Grades AC-10 and AC-20 were used. The main reason for selecting the two types of asphalt is that these two types of asphalt are the most commonly used in the United States. The asphalt was obtained from the local asphalt plant. The refinery is unkown.

The physical properties of AC-10 and AC-20, including those provided by the supplier, are summarized in Table 4.3. The values from these tests comply with the INDOT specifications.

Table 4.3 The Physical Properties of AC-10 and AC-20.

Test	AC10 (Requirements of Specification)	AC20(Requirements of Specification)
Penetration @ 77°F (25°C) (0.1 mm), 100g, 5 sec.	87 - 106 (70 - 140)	63 - 65 (50 - 110)
Kinematic Viscosity @ 275°F (135°C), Centistokes, Min.	316 (250)	406 (300)
*Absolute Viscosity @ 140°F (60°C), Poise, Max.	2670 (4000)	5497 (8000)
Flash Point, Cleveland Open Cup, °C, Min.	231 (218)	260 (232)
Solubility in Organic Solvents, %, Min.	99.9 (99.0)	99.95 (99.0)
*Ductility @ 25°C, 5 Cm/min, Cm, Min.	60 (60)	60 (40)

* Residue from from the Thin-Film Oven test.

4.3 Pyrolized Carbon Black (PCB)

Pyrolized Carbon Black (PCB) was provided by Wolf Industries, Brazil, Indiana. Wolf Industries has obtained oil from the waste tire burning process and pyrolized carbon black is a by-product of the pyrolysis of waste tires. Carbon black and oil are the main products obtained from the pyrolysis of waste tires. Yields from tire pyrolysis vary with the facility and the method used. Tire pyrolysis typically yields 55% of oil, 25% of carbon black, 9% of steel, 5% of fiber and 6% of gas.

The information provided from Wolf Industries specified that pyrolysis is a method of decomposing tires by a "cooking" process in order to break down the tire rubber into salable byproducts. The process by which pyrolized carbon black is produced is highly protected as confidential and proprietary by the manufacturer. Only limited and general information is available from Wolf Industries. Figure 4.2 outlines the processing diagram for the pyrolysis of waste tires in the production of pyrolized carbon black by Wolf Industries.

Pyrolysis also is called destructive distillation, thermal depolymerization, thermal cracking, carbonization, or cooking. There are several other methods of tire pyrolysis. The pyrolized carbon black used in this study is obtained from the most common process, reductive (retort) pyrolysis. A schematic of the operation process of pyrolized carbon black is depicted in Figure 4.3.

Pyrolized carbon black contains a maximum of 9% ash content, 4% sulfur content, 12% minimum butadine copolymer content(nitrile rubber),and 75% carbon black. This type of carbon black could partially replace commercial carbon blacks for the preparation

Tire Collection and Handling

- Semi-Tractor collects used tires for 90 days.
- Tire inspection (only light weight tires are accepted)

Production Area

- The tires are sent by the conveyor.
- The tires are cut and cleaned.
(About 6" in length)
- The cut tires are sent to the main machinery
for next process.

The Retort

- The tire bundles evaporate at approximately
800°F. (The Pyrolysis Process)
- As a result, the solids in the tires, CARBON BLACK
and steel, fall to the bottom of the tubes.

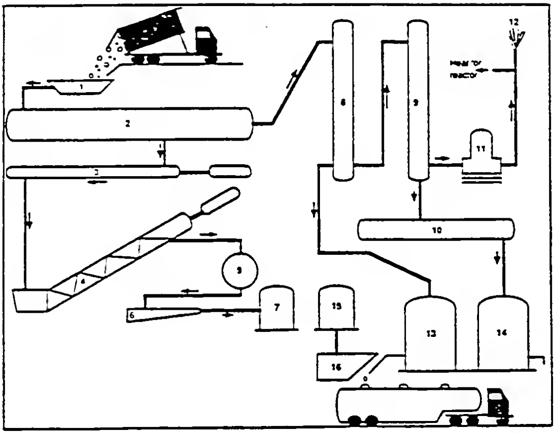
End Processing of Solid

- The CARBON BLACK and steel are moved
through a water cooled table to begin the cooling
process.
- The upgraded carbon black is sent to a wet pulverizer
and milled to reduce the particle size.

Final Processing of Vapors and Liquids

- The separation of volatiles and non-volatiles.
- The recovery of oil through a distillation process.
- The distillation of the condensable vapors.
- Flue gas from the process.

Figure 4.2 The Processing diagram of the Pyrolysis of Waste Tire by Wolf Industries



Note : 1=Feed conveyor, 2=Vacuum reactor, 3=Cooling screw, 4=Discharge Screw, 5=Crusher, 6=Vibratory screen, 7=Carbon black handling system, 8=Heavy oil quencher, 9=Light oil quencher, 10=Decanter, 11=Vacuum pump, 12=Elare stack, 13=Heavy oil storage, 14=Light oil storage, 15=Magnetic separator, 16=Steel recovery bin.

Figure 4.3 Schematic of the Operation Process of Pyrolized Carbon Black (After Roy et al., 1990)

of low-grade rubber products (Roy et al., 1990). The gradation of pyrolized carbon black is 90% or greater through the #200 sieve. The determination of particle size distribution passing the #200 using an hydrometer was impossible because carbon black did not mix with water and floated on the water surface. Material test results provided by Wolf Industries show that pyrolized carbon black is insoluble in water. The particle size and surface area of pyrolized carbon black passed through a mill grinder are shown in Table 4.4.

Table 4.4 The Particle Size and Surface Area of Pyrolized Carbon Black (Mill Ground)

Name of the Products	Rg (Å), Particle Size	Specific Surface Area, gm/cm^3	Large Scale df	Large Scale Rg (μm)
BC 100	430	157	1.9	0.87
BC 200	343	188	2.3	0.52
BC 500	439	159	2.4	0.70
WC 500	230	338	1.7	N/A
NC 339	304	187	N/A	(> 0.49)

NOTE : NC 339 is a pure carbon black and listed for comparison to pyrolized carbon black.

General properties of a similar carbon black sample produced during vacuum pyrolysis of scrap tire are also summarized in Table 4.5. From the environmental point of view, the pyrolized carbon black may form toxic materials (carbon dioxide and carbon monoxide) however as stability is high, this may not occur easily.

Table 4.5 General Properties of Carbon Black Produced during Vacuum Pyrolysis of Used Tires. (After Roy et al., 1990)

Iodine Index (mg/g)	144.2 - 151.4
DPB Adsorption (ml/100g)	84.6 - 93.0
Heat Loss at 105 °C (%)	57.1 - 60.6
Tint Strength (% ITRB)	15.5 - 17.0
Ash (%)	4.9 - 3.3
Volatile Matter	2.5 - 3.0

NOTE : Ultimate temperature was 525°C and total pressure varied between 1.5 and 4.5 kPa. (Feedstock included both regular and steel belt used tire samples.)

The pyrolized carbon black is blended with asphalt as received. The particles of pyrolized carbon black are much coarser than high structure HAF (High Abrasion Furnace) type carbon black, however, most of the coarse particles are easily broken down by normal pressure. The color is lighter than HAF type carbon black.

4.4 Carbon Black (CB)

Carbon black (CB) was purchased from CABOT Industry, Boston, Massachusetts. The trade mark is REGAL 300R. Carbon black was discovered in 1915 (Rostler et al., 1977). About 40 different types of commercial carbon black are sold in the current market. Carbon black has been used in many industries such as for ink, plastic, rubber, and electronic wires. Among those industries, the largest consumer is the rubber industry. The quality of carbon black is determined by its micro structure, surface area and particle size.

It is generally known that the high quality carbon blacks provide small particle size and large surface area.

According to Powell (1968), definition of carbon black, in terms of manufacturing, is that " formed by incomplete combustion of many organic substances such as solid, liquid and gas". There are four types of carbon black: furnace carbon blacks, channel blacks, thermal blacks, and lamp blacks. Each carbon black may be composed of several grades determined by the particle size and the specific surface area. Furnace blacks are made in a furnace by partial combustion of hydrocarbons; channel blacks are manufactured by impingement of natural gas flames on channel irons; thermal blacks are produced by thermal decomposition of natural gas; and lamp blacks are collected from soot lamps or burning candles.

The carbon black used in this study is high structure high abrasion furnace (HAF) type carbon black. It is known that this carbon black is the second best carbon black in the market. The reason for choosing the high structure HAF type is that several researchers have reported that improvement of temperature susceptibly and of rutting and cracking resistance was achieved by carbon black modified asphalt of the high structure HAF type (Khosla, 1991, Yao and Monismith, 1986, Vallerga and Gridley, 1980, Rostler et al., 1977).

Typical properties of several carbon blacks are summarized in Table 4.6. The alphabetical code designations in Table 4.6 are used in the rubber industry for product identification (Rostler et al., 1977). It can be noted from the summary presented that the particle size of all the carbon black is orders of magnitude smaller than ground limestone.

The increase of surface area is highly significant as the mean particle diameter decreases. Particle size and structure are the two most important parameters to define the performance characteristics of carbon black. When the particle size becomes smaller, dispersibility becomes more difficult. This type of carbon black needs a high speed quality of mixer to ensure proper mixing. When higher structure carbon black is used, the dispersibilty becomes easier. Typical performance characteristics of carbon blacks are illustrated in Figure 4.4.

The analytical specifications of REGAL 300R carbon black from the CABOT industry are shown in Table 4.7. As can be seen in Table 4.7, density is 12.5 ± 3 pcf, ash content is a maximum of 1.0 percent, iodine index is 76 ± 5 mg/g, Dibutyl Phthalate absorption is 85 ± 5 cc/100g, and tint strength is 113 ± 5 % ITRB. Mean particle diameter ranges from 100 to 500 nanometers, and surface area is between 15 and 100 m^2/g. Rostler et al. (1977) reported that "the particle aggregates of carbon black have an infinite variety of geometric forms from clustered to branched and filamentous configurations. Carbon black is hydrophobic material, and nearly pure carbon black contains less than 3% of other elements."

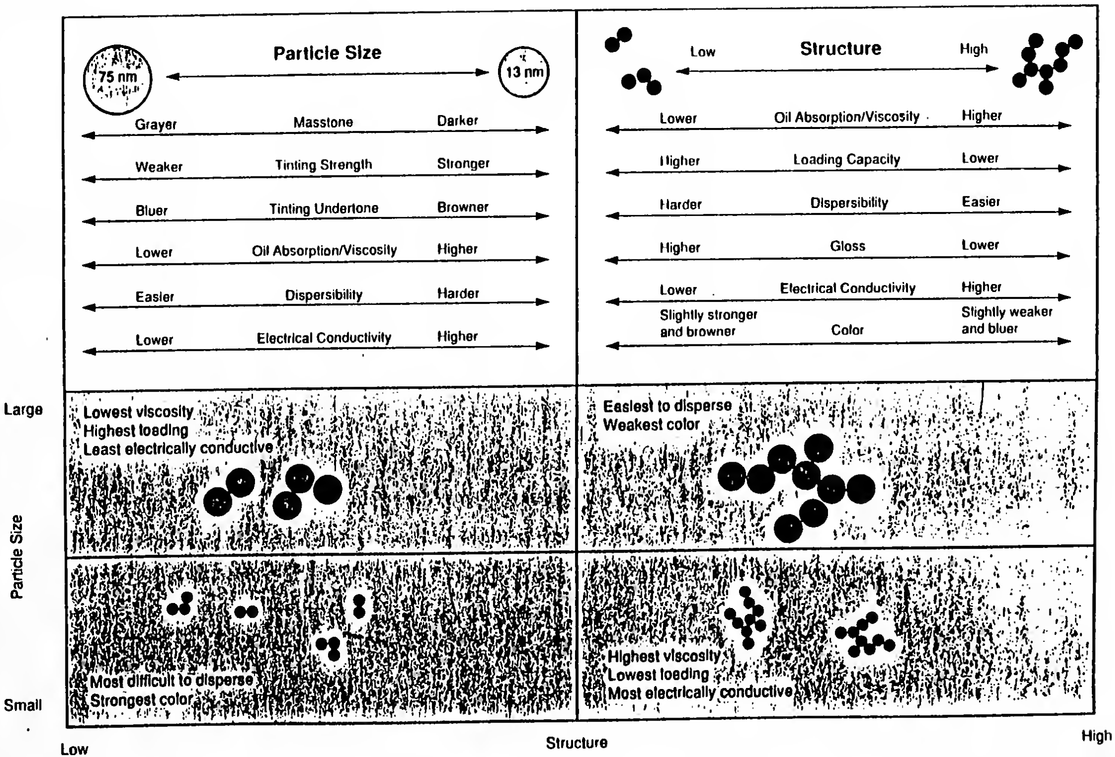


Figure 4.4 Typical Performance Characteristics of Carbon Black (After CABOT, 1994)

Table 4.6 Summary of Typical Properties of Carbon Blacks and Fillers (After Rostler et al., 1977)

Symbol	Type	Mean particle Diameter, nm	Surface Area m^2/g	DBP Absorption cc/100g
SAF	Super Abrasion Furnace Black	19	145	115
HAF-HS	High Structure, High Abrasion Furnace Black	26	90	125
HAF	High Abrasion Furnace Black	29	80	103
FEF	Fast Extruding Furnace Black	42	40	120
SRF	Semi-Reinforcing Furnace Black	60	25	75
MT	Medium Thermal Black	500	7	33
	Kaolin Clay	100 - 5000	5 - 10	25
	Ground Limestone	35000	3.1	N/A

NOTE : 1. Mean Particle size : Estimate of average "particle" or nodule size from electron micrographs.

2. Surface Area : Measured by nitrogen adsorption, BET method.

3. DBP Absorption : Measure of void volume of bulk carbon black using dibutylphthalate as absorbate.

Table 4.7 Analytical Specifications for REGAL 300R Carbon Black (After CABOT Industries,1994)

Property	Test Method	Specification
Density (lb/ft^3)	ASTM D1513	12.5 ± 3.0
Ash (%)	ASTM D1506	1.0 max
Iodine Index (mg/g)	ASTM D1510	76 ± 5
Dibutyl Phthalate Absortion (cc/100g)	ASTM D2414	85 ± 5
Tint Strength (% ITRB)	ASTM D3265	113 ± 3.0

CHAPTER 5

EXPERIMENTAL WORK

5.1 Plan of Test

Two types of asphalt, AC-10 and AC-20, Indiana #9 binder aggregate (limestone) and two carbon black modifiers (pyrolized carbon black and commercial carbon black) were employed to evaluate the characteristics and performance of carbon black modified asphalt concrete mixtures. Table 5.1 shows the test matrix. As can be seen in Table 5.1, a total of 18 sets of mixtures were prepared. All specimens were produced according to ASTM standards and MS-2 requirements.

The optimum binder content for each cell was determined using the Marshall Method. The effect of inclusion of pyrolized carbon black and carbon black was evaluated and compared in terms of air-voids, VMA, VFA, stability and flow for the initial stage. The optimum binder contents determined were used in the preparation of specimens for the subsequent tests. The Gyratory Testing Machine (GTM) and Material Testing Systems (MTS) were used to determine and to compare the characteristics and the performance of each mixture. Figure 5.1 shows the schematic flow chart of the test plan .

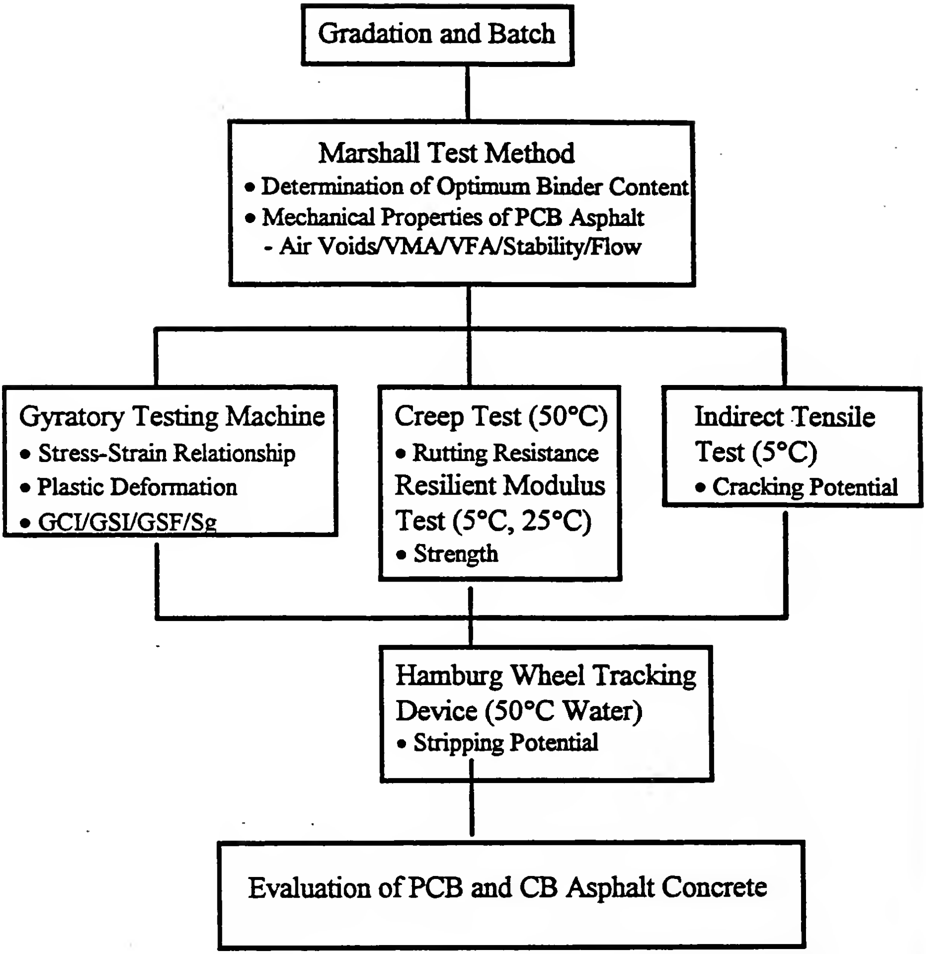


Figure 5.1 Schematic Flow Chart of Test Plan

Table 5.1 Matrix of the Test Plan.

	Indiana #9 Binder Aggregate (Limestone)								
	Additives								
	Pyrolized Carbon Black Content (%)					Carbon Black Content (%)			
Asphalt	0 %	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %
AC-10									
AC-20									

The stress strain relationship and the plastic deformation of the mixtures were obtained from the Gyratory Testing Machine. Specimens for the Gyratory Testing Machine were based on the optimum binder content determined by the Marshall Method. The Gyratory Compactibility Index (GCI), Gyratory Shear Index (GSI), Gyratory Shear Factor (GSF), Gyratory Shear (Sg), and Gyratory Compression Modulus (Eg) were determined and compared.

For creep, resilient modulus and indirect tensile testing, Marshall compacted specimens at an air void content of 6% were used. Creep testing and resilient modulus testing were carried out with a Material Testing System (MTS) model 810 with environmental chamber. For stripping testing, the Hamburg wheel tracking device was used.

5.2 Preparation of Binder

Heated pyrolized carbon black and carbon black were blended separately with heated asphalt cement. The content of pyrolized carbon black and carbon black is based on

the weight of asphalt. Mixes of 5%, 10%, 15%, and 20% of pyrolized carbon black and carbon black were adopted for the study because a previous carbon black modified asphalt concrete study (Yao and Monismith, 1986) showed that carbon black contents between 10% and 15% have resulted in enhanced rutting resistance and less cracking, and also because it was difficult to blend pyrolized carbon black and carbon black with asphalt cement when admixtures were greater than 20%.

The following procedures, recommended by Khaedywi (1988), were used and modified for the preparation of pyrolized carbon black and carbon black binders.

1) Pyrolized carbon black and carbon black were heated separately in stainless steel bowls to a temperature between 290°F and 300°F (145°C and 150°C)

2) Measured amounts of pyrolized carbon black and carbon black were blended with the heated asphalt to yield nominal concentrations of 5%, 10%, 15% and 20% by weight of asphalt. A hot plate was used for blending operations to maintain temperature and to disperse pyrolized carbon black and carbon black properly.

3) A mechanical hand mixer was used to mix pyrolized carbon black and carbon black binder with the heated asphalt.

4) Mixing of pyrolized carbon black and carbon black was continued until the modified binder showed a uniform mix condition.

5) After the mixing was completed, the modified binder was kept in an oven at 290°F and 300°F (145°C and 150°C) to remove air entrained during the mixing process. A 2 or 3 minute period was required.

6) The prepared binder was mixed with the hot aggregate to make test specimens at 275°F (135°C).

Significant segregation of pyrolized carbon black and carbon black were observed during testing. Pyrolized carbon black was observed to settle more rapidly than carbon black, which is attributed to the difference in specific gravities between the two materials. According to the statistic analysis of specific gravity of mixtures, the specific gravity of pyrolized carbon black is 1.486 and carbon black is 1.945. In order to manufacture an homogeneous binder, the modified binder was remixed before the binder was added to the aggregate. A hot spatula was used to add the binder to the aggregate; the binder was agitated vigorously to disperse properly and to ensure a homogeneous mixture.

5.3 Marshall Test Method

5.3.1 Background and Equipment

Since its development in 1940's the Marshall Method has increasingly been accepted by the highway agencies throughout the world to design and control bituminous paving mixtures (Kandhal and Koehler, 1986). In spite of its shortcomings, at the present time about 80% of the state highway agencies use this method because of its simple

operation and economical equipment. Figure 5.2 shows the states which currently use the Marshall Test Method as design criteria.

The asphalt compactor used for the Marshall Test Method was the SoilTest Model AP-850. This compactor has a separate counter unit to minimize the impact from the hammering. The manufacturer states that the compactor simulates hand compaction while maintaining repeatability in compaction results. The trip mechanism is designed so that the hammer falls the same distance for every stroke, and a dead weight arrangement on top of the hammer assembly eliminates rebound effects. For stability and flow tests ASTM D 1559, SoilTest Marshall Stability Tester Model AP-170C, and ELE model L6512 LINSEIS chart recorder were employed. The strain rate applied to the specimen in the Marshall stability tester was set at 2 inch (50.8 mm)/min. according to ASTM D1559 and all test procedures followed ASTM D 1559 and MS-2.

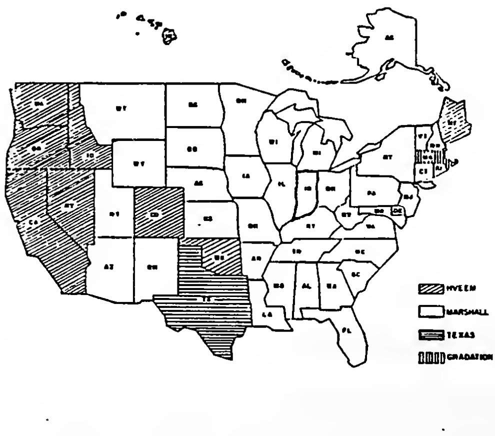


Figure 5.2 States which use the Marshall Test Method (After Kandhal and Koehler, 1986)

5.3.2 Mix preparation

The mix preparation of Marshall specimens is that of ASTM D1559. Asphalt was heated in a 5 gallon can with lid, and the heated asphalt was transferred to 5 quart cans for testing. The 5 quart can was heated as needed.

The asphalt was heated between 290°F and 300°F (145°C and 150°C) for approximately 1 hour to help mixing with aggregate, which in turn would provide a good coating and ensure an homogeneous mixture. This is the temperature used in simulated plant mixing. The Hobart mechanical mixer was used at the low speed setting.
The entire mixing time ranged between 5 and 8 minutes. Lesser binder contents (such as 3.5% and 4 %) required more mixing time than the others.

The mass of 1200 grams of aggregate for one batch was stored in a plastic bag prior to the test. The aggregate in the plastic bag was poured into the stainless steel bowl and heated between 3 hours and 5 hours to remove the moisture in the aggregate. Three samples were prepared for each mixture. In order to have a consistent specimen, the minimum of the mass of aggregate after heating was limited to 1197.4 grams. The aggregate used for this study had very little absorption; therefore, compaction was carried out immediately after the mixing was completed.

5.3.3 Compaction

The mix design method for the Asphalt Institute (MS-2) specifies three levels of compaction work. These levels of compaction were applied in accordance with the Indiana Department of Transportation (INDOT). Specifications and other procedures followed

were ASTM D1559 and MS-2. However, INDOT specifies only one level of compaction, i.e., 75 blows per side. The compaction temperature was 230°F (110°C).

The compacted samples were cooled at room temperature for 12 to 15 hours. The cooled samples were extruded from the molds and the subsequent tests were performed; bulk specific gravity (ASTM D2726), Marshall stability (MS-2), Marshall flow (ASTM D2041), and maximum theoretical specific gravity (ASTM D2041).

5.4 Gyratory Testing Machine

5.4.1 Background and Equipment

The gyratory testing machine has been accepted as an effective and practical tool in the evaluation of characteristics and performances of bituminous mixtures. The Strategic Highway Research Program (SHRP) selected the SHRP gyratory testing machine as a standard laboratory compaction device, because it is proven from many test results that this machine simulates field compaction reasonably well. The vertical pressure, gyration angle and number of gyrations can be controlled to simulate field compaction equipment and subsequent traffic.

Figure 5.3 shows a schematic of the U.S. Army Corps of Engineers gyratory testing machine, which was used in this study. The gyratory testing machine produces test specimens by a kneading compaction process. This is more realistic than an impact type compaction. Therefore, the test results of the gyratory testing machine provide realistic stress strain properties for mixtures.

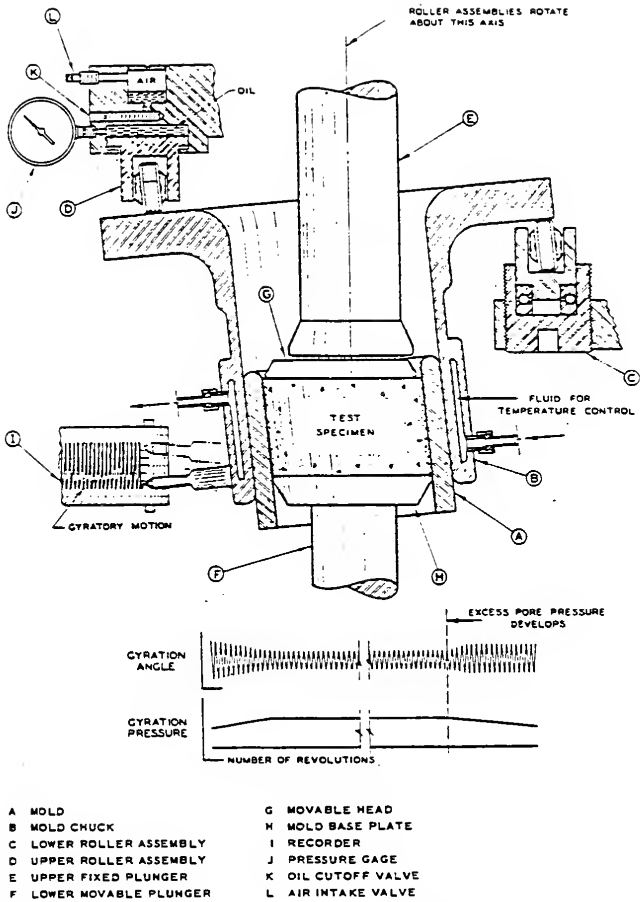


Figure 5.3 Schematic of U.S. Army Gyratory Testing Machine (After U.S. Army Corps of Engineers, 1962)

The gyratory testing machine was developed in 1962 by the U.S. Army Corps of Engineers. It has found application in the design and evaluation of asphaltic mixtures. This machine also has been used with soil to evaluate the properties of compacted soils.

Two kinds of gyratory testing machines have recently become available. One is the U.S. Army Corps of Engineers gyratory testing machine and the other is the SHRP (Strategic Highway Research Program) gyratory testing machine. The basic idea and the operation of the machines are essentially identical. The only difference is that the SHRP gyratory machine has a fixed plate, whereas the U.S. Army Corps of Engineers gyratory testing machine is freely rotated. While the SHRP gyratory machine is used for the compaction of the specimen, the U.S. Army gyratory machine has been used for both testing and compaction of the specimen. Figure 5.4 illustrates the gyratory testing machine instrumentation block diagram.

Referring to the manual from the Engineering Developments Company Inc.(1993), mold A containing a test specimen is clamped in position in the flanged mold chuck B. Vertical pressure on the test specimen is maintained by upper ram E and lower ram F acting against heads G and H, respectively. Head G acts against a roller bearing and is therefore free to slip while head H is fixed. Since the mold is securely held by the chuck, a gyratory motion (shear strain) is imparted to mold chuck B by rollers C and D as they travel around the flanged portion of the chuck. These bearing surfaces are lubricated surfaces. Roller C is adjustable in elevation to permit setting any desired gyratory angle (shear strain), but is maintained at a fixed elevation during the operation of the machine. Roller D maintains an essentially fixed elevation when using the oil-filled cell, but may

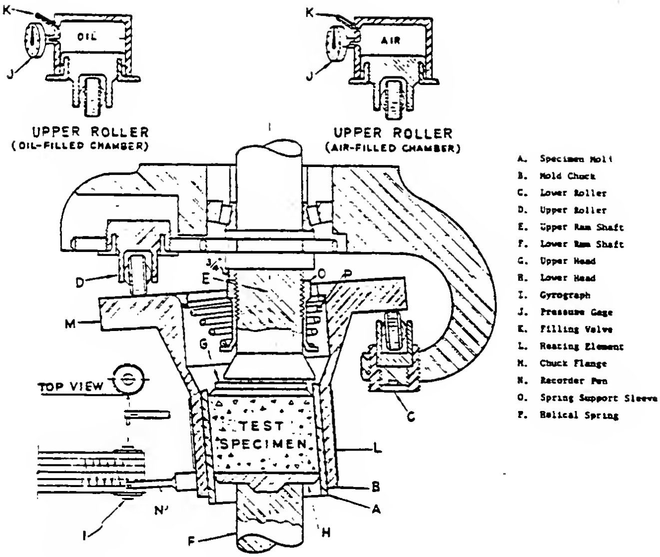


Figure 5.4 Gyratory Testing Machine Instrumentation Block Diagram (After U.S. Army Corps of Engineers, 1962)

vary slightly in elevation when using the air-filled cell. The oil-filled roller was used for this study. Upper rollers D, containing the pressure cell, emit signals that are transmitted by telemetry and digitized by the tall panel meter N.

The gyratory motion (shear strain) is sensed by angular transducer I, and recorded by recorder E. This recording of shear strain is called as a Gyrograph. Sample gyrographs are shown in Figure 5.5.

The U.S. Army Corps of Engineers 8A/6B/4C model was employed for the study. This gyratory testing machine is able to accommodate three different sizes of diameters of specimens (8 inches, 6 inches, 4 inches). The model number represents a diameter of specimen size.

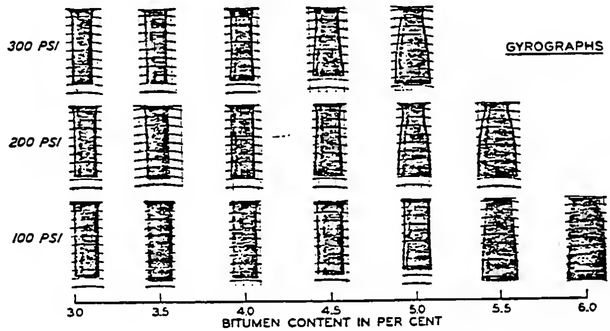


Figure 5.5 Examples of Gyrograph

5.4.2 Mix Preparation

Mix preparation for the gyratory compaction specimens followed the same procedures as for the Marshall tests. Other procedures were carried out in accordance with ASTM D3387 and the manual provided by the Engineering Developments Company Inc. (1993). The masses of 1200 grams of aggregate and optimum binder content were used to ensure the size of specimen for 4 inch (101.6 mm) diameter and approximately 2.5 inch (63.5 mm) height. The gyratory testing machine was turned on 2 hours before the compaction started. The chuck temperature was kept at 140°F±5. Samples were prepared for each optimum mix according to the recommendation of McRae (1993).

5.4.3 Compaction

It is well known that the gyratory testing machine provides strains reasonably similar to the plastic ones produced by traffic loads. The variation of the plastic behavior by traffic loads can be monitored by the different revolutions, i.e., gyratory compaction. The SHRP recommendation is 230 revolutions (SHRP, 1994).

A 4 inch (101.6 mm) diameter mold was used for the preparation of each specimen. A 1.25° angle of gyration and a 120 psi (827.4 Kpa) normal pressure were selected to produce the specimens. Although 1° is most commonly used, the angle of 1.25° was chosen to simulate the worse condition. The normal pressure (ram pressure) corresponds to the maximum anticipated tire contact pressure, since the theoretical stress for compaction and maximum induced shear is based on the concept of simulating the field conditions for the test. (Zhang et al., 1994).

A value of 250 revolutions was selected for the ultimate compaction efforts because, as mentioned earlier, SHRP (1994) recommend 230 revolution as the ultimate traffic densification. According to McRae's (1993) recommendation, if the variation of densification of the specimen is not greater than 1 pcf after an additional 100 revolutions, compaction is completed. This condition was achieved between 200 revolutions and 250 revolutions for most samples.

The variation of roller pressure and height of sample were monitored and recorded at every 50 revolutions to check the effects of subsequent loads and inclusion of different ratios of pyrolized carbon black and carbon black. The roller pressure and the height of sample were measured at four roller positions separated in positions by approximately 90°. The height of sample, gyratory angle, and applied pressure were recorded by the gyrograph. After the compaction was completed, the sample was extruded from the mold. The compacted samples cooled in the laboratory temperature (67°F to 72°F) for 12 hours prior to the bulk specific gravity test. The bulk specific gravity tests were performed in accordance with ASTM D 2727 to verify the existence of 6 % air voids in the compacted sample.

5.5 Dynamic Confined Creep Test

5.5.1 Background and Equipment

Present asphalt design methods lack accuracy in determining the full effects of variation in environmental and loading condition and of pavement performance. Significant progress in hot mix design allows for test results to be analyzed quantitatively as well as

qualitatively. Qualitatively, the creep modulus at the specific temperature is used to evaluate the relative improvement between mixes (Wahhab and Khan, 1991).

Creep is defined as the continuous time dependent deformation under constant stress or load. Creep test data characterize the permanent deformation properties (rutting) of asphalt mixtures. The dynamic confined creep test has been developed to predict permanent deformation in asphalt concrete mixtures more reasonably in the laboratory (Gablielson, 1992). Creep compliance and mix stiffness are good parameters for relative mix stability and the expected rut depth or permanent deformation (Finn et al., 1983).

Tests were carried out on a Materials Testing System (MTS), with feed back control hydraulic tester and with a temperature controlled environmental chamber. As the loading and measuring device, a MTS model 810 was employed. Data were collected and analyzed by Automated Testing System (ATS) software. Figure 5.6 shows the schematic of the Materials Testing System.

The front panel of the MTS is composed of four different panels; the oscilloscope, the temperature controller, the analog chassis, and the hydraulic control, as can be seen in Figure 5.6. The oscilloscope, Tektronix 2225, 50 MHz, provides a visual check that the appropriate test frequency is applied throughout the test.

The temperature controller described in the MTS manual (1994) is the microprocess based MTS 409.80, and is used for controlling the environmental chamber. The control module for the temperature controller receives a thermocouple input, and processes the heating or cooling so that the environmental chamber supplies the necessary temperature for testing. A block diagram of the temperature controller and the

environmental chamber are shown in Figure 5.7. Figure 5.8 shows a 497.01 analog chassis with the 497 modules installed. The chassis contains 16 user slots and two dedicated bud board slots. The module provides interlock control, communication, transducer conditioning, and valve drive. The interlock controller allows test stations to have independent interlock and hydraulic status signals. The microprocessor based communication module provides data conversion between the system host and module residing on the 497 parallel bus. The function provided by the transducer conditioning are transducer excitation and output signal amplification. Both low and high level transducers can be used by the installation of AC/DC conditioners. Valve drivers provide drive current for servovalves according to command inputs received for each channel. Critical parameters are programmed through the 497 chassis bus.

The 497.05 hydraulic control panel is used to control hydraulic power supply. The functions provided by the hydraulic control panel are; 1) control of up to four independent hydraulic service manifolds; 2) hydraulic power supply control; 3) interlock shutdown and latched indicators to show interlock status; 4) programmable interlock station assignment; 5) electrical power outputs to the hydraulic service manifolds and a 497.01 analog chassis. The hydraulic control panel functions are controlled by its front panel controls or by the host computer.

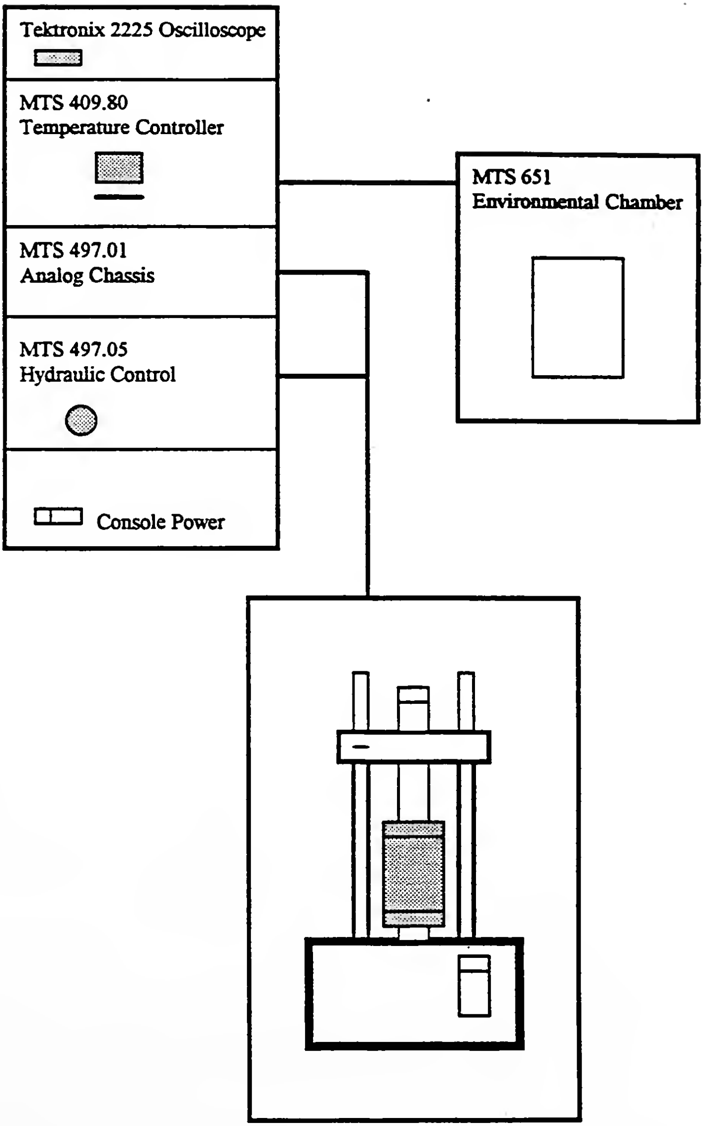


Figure 5.6 Schematic of the Material Test System

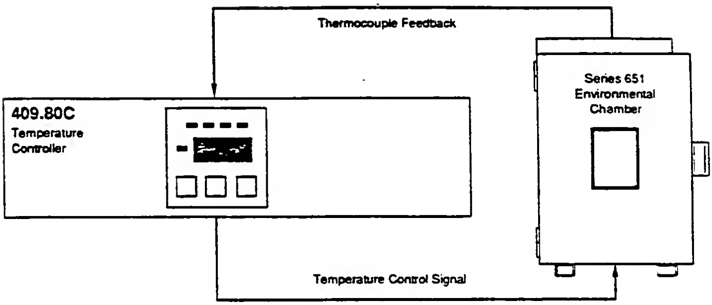


Figure 5.7 Block Diagram of the Temperature Controller and Environmental Chamber (After MTS Manual, 1994)

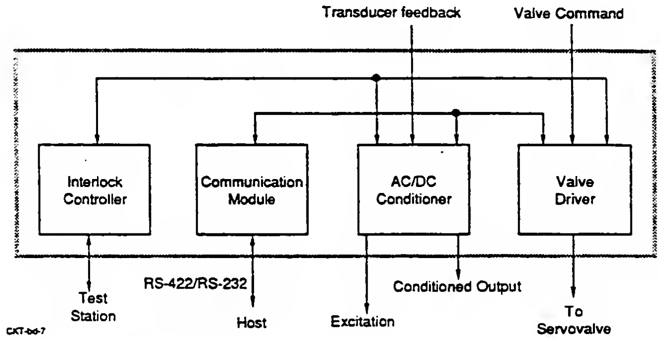


Figure 5.8 497.01 Analog Chassis with the 497 Modules Installed (After MTS Manual, 1994)

5.5.2 Concept of the Creep Deformation in Asphalt Concrete

Asphalt concrete is subjected to creep deformation by the repeated loads (Brown and Foo, 1994). Perl et al (1983) suggested that , the total strain (ε_t) of asphalt concrete consists of four components; elastic strain, plastic strain, viscoelastic strain and viscoplastic strain. Elastic and plastic strain are time independent, viscoelastic and viscoplastic strain are time dependent. While elastic and viscoelastic strain are recoverable, plastic and viscoplastic strain are irrecoverable. Therefore, the total strain ε_t can be expressed as four components;

$$\varepsilon_t = \varepsilon_e + \varepsilon_p + \varepsilon_{ve} + \varepsilon_{vp}$$

where, ε_e = Elastic Strain (Recoverable and Time-independent)

ε_p = Plastic Strain (Irrecoverable and Time-independent)

ε_{ve} = Viscoelastic Strain (Recoverable and Time-dependent)

ε_{vp} = Viscoplastic Strain (Irrecoverable and Time-dependent)

Figure 5.9 shows the creep behavior of asphalt concrete. The quantity (t_1) is referred to as the loading duration and $(t_2 - t_1)$ is referred to the rebounding duration. When the load is applied at $t = t_o$, a strain ε_o is generated immediately. This strain consists of the elastic and plastic components as shown in Figure 5.9. During the loading duration ($t_o \leq t \leq t_1$), the strains containing viscoelastic and viscoplastic occur. If the load is removed ($t = t_1$), the elastic strain is recovered instantaneously. In the rebound period ($t_1 \leq t \leq t_2$), the viscoelastic strain is recovered. It can be noted from Figure 5.9 that at the end of the rebound period, the permanent creep strain consists of the irrecoverable plastic and

viscoelastic strain. The permanent creep strain and applied stress are used to calculate the mix stiffness (stiffness of the mixtures, Smix) as a function of loading times (seconds). In order to determine viscoelastic characteristics of mixtures, creep compliance can be estimated by using the permanent creep strain and applied stress. The creep compliance is the inverse of the mix stiffness.

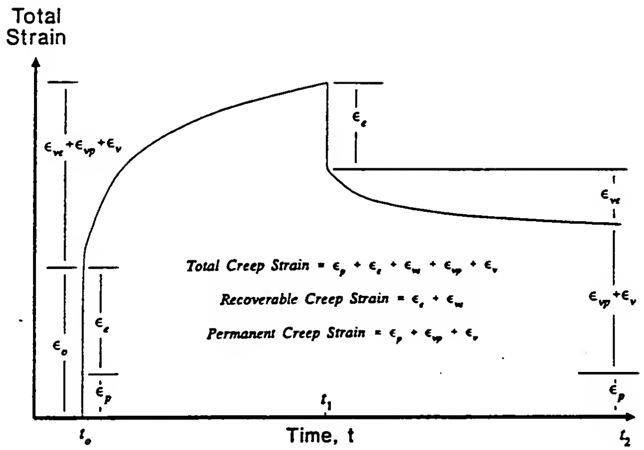


Figure 5.9 The Creep Behavior of Asphalt Concrete (After Perl et al, 1983, Brown and Foo, 1994)

5.5.3 Preparation of Specimens

The specimens were reproduced with the optimum binder contents determined from the Marshall method. The 4 inch diameter Marshall specimens were compacted with 75 blows per face. Bulk specific gravity was measured to check that the air void was approximately 6 percent. The deviation of air voids was limited to ±1 %. Table 5.2 shows the condition of each specimen prepared for test.

5.5.4 Testing protocol

Various creep test methods have been used because a test procedure has not yet been standardized. Static Unconfined Creep Test, Static Confined Creep Test, Incremental Loading Creep Test, Dynamic Unconfined Creep Test, and Dynamic Confined Creep Test have been used by researchers. Gablielson (1992) has performed an extensive study on various creep tests and recommended the Dynamic Confined Creep Test. The Dynamic Confined Creep Test simulates the field condition resonablely well. The test procedure and method were followed in accordance with his recommendations. However, modifications to the test were made as needed for the testing in this study.

The specimens were conditioned at temperature 122°F (50°C) in an oven for 2.5 hours. The heated specimen was placed in the triaxial chamber with dense paper on both ends to reduce the friction between the specimen and the loading cell. Next, the specimen was wrapped by the rubber membrane to ensure that the specimen was subjected to the constant confinement pressure. The triaxial stress conditions were applied to the specimen. A 20 psi confinement stress was applied in the environmental chamber for 30 minutes, 120 psi axial stress was used. After 10 seconds, the deviatoric stress of 100 psi was applied for

3600 cycles, including a 15 minute rebound period. The time of a repeated loading cycle was 1.0 second, which consisted of 0.1 second loading and 0.9 second unloading duration. The summary of the test protocol is as follows:

Type of Creep Test : Dynamic Confined Creep (Repeated Confined Loading)

SAMPLE: 2" radius x h" height (approx 2.5")

TEST ENVIRONMENT:

20 psi confining pressure
122°F(50°C) test temperature
Rubber membrane

SAMPLE SET-UP:

Condition at test temperature in oven for 2.5 hr.
Place sample in frame with smooth, dense paper on ends (or two layers of plastic with grease)

TEST PROTOCOL:

Set-up:

- Apply confining pressure (20 psi)
- Surround with environmental chamber
- Hold for 30 minutes

Test (Automatic through ATS):

- Apply 1.5 psi (0.084 kN) resistance load
- Apply 30 cycles at 10 psi (0.559 kN) axial (0.1 sec load + 0.9 sec unload)
- 10 seconds rest at 1.5 psi (0.084 kN) resistance load
- [Record on] Apply 3600 cycles at 120 psi (6.710 kN) axial (0.1 sec load + 0.9 sec unload)
- Rest 15 minutes at 1.5 psi (0.084 kN) resistance load [Record off]

End Test

RECORDING SCHEDULE:

Data: Axial Strain

Collection Schedule:	Cycles	Frequency
	0 - 30	0.5 sec (61)
	40 - 300	23.0 sec (14)
	350 - 3600	50.0 sec (66)
	3601 - 3630	1.0 sec (30)
	3635 - 3670	5.0 sec (8)
	3680 - 3900	23.0 sec (12)
	3950 - 4500	50.0 sec (12)

Table 5.2 The condition of Specimens for Creep Testing

Sample I.D	Bulk S.G	Max.Theoretical S.G.	Air-Voids (%)	Height of Specimens(in.)
AC10	2.429	2.576	5.7	2.555
AC10+5%CB	2.442	2.576	5.2	2.577
AC10+10%CB	2.436	2.576	5.4	2.566
AC10+15%CB	2.442	2.580	5.3	2.564
AC10+20%CB	2.447	2.578	5.1	2.603
AC10+5%PCB	2.430	2.573	5.6	2.576
AC10+10%PCB	2.435	2.574	5.4	2.598
AC10+15%PCB	2.444	2.568	5.2	2.557
AC10+20%PCB	2.413	2.563	5.9	2.611
AC20	2.414	2.590	6.8	2.539
AC20+5%CB	2.426	2.573	5.7	2.538
AC20+10%CB	2.435	2.571	5.3	2.565
AC20+15%CB	2.440	2.568	5.0	2.565
AC20+20%CB	2.423	2.562	5.4	2.560
AC20+5%PCB	2.412	2.573	6.3	2.559
AC20+10%PCB	2.408	2.575	6.5	2.567
AC20+15%PCB	2.440	2.564	5.2	2.564
AC20+20%PCB	2.421	2.558	5.4	2.612

5.6 Resilient Modulus Test

5.6.1 Background and Equipment

The resilient modulus provides the stiffness of the mixtures, since it has been found that the resilient modulus at low temperatures is somewhat related to the cracking potential of pavement. The stiffer mixtures at low temperatures tend to crack earlier than the more flexible mixtures (Robert et al., 1991). The resilient modulus was used to determine the strength of the mixtures at two different temperature in this study.

The same equipment which was used in the creep test was used for the resilient modulus test. A closed loop, servo-hydraulically controlled loading system was used for the test. The MTS model 643.01A, resilient modulus fixture, was employed to determine the modulus. Figure 5.10 illustrates an example of the installation of a specimen for a resilient modulus test. The horizontal extensometer measures the horizontal deformation of the specimen and the vertical extensometer measures the vertical deformation. The deformations were used in estimating the resilient modulus of the mixture.

5.6.2 Preparation of Specimens

After the completion of the creep test, the same specimens (4 inch diameter and 2.5 inch high) were conditioned at temperatures of 41°F (5°C) and 77°F (25°C) for 24 hours prior to the test. The conditioned specimens were placed inside an environmental chamber at testing temperature to perform the test.

5.6.3 Testing Procedures

The resilient modulus tests were carried out on diametrical specimens, in the indirect tension mode at 41°F (5°C) and 77°F (25°C). The applied loading magnitudes

were determined within 10 to 30 percent of the indirect tensile strength of the specimens prior to testing. The one second of repeated loading cycle, which consisted of 0.1 second loading and 0.9 second unloading duration was applied along the vertical diameter of the test specimen for 200 seconds. The corresponding deformation was measured across the horizontal diameter. The testing procedures were followed in accordance with ASTM D4123.

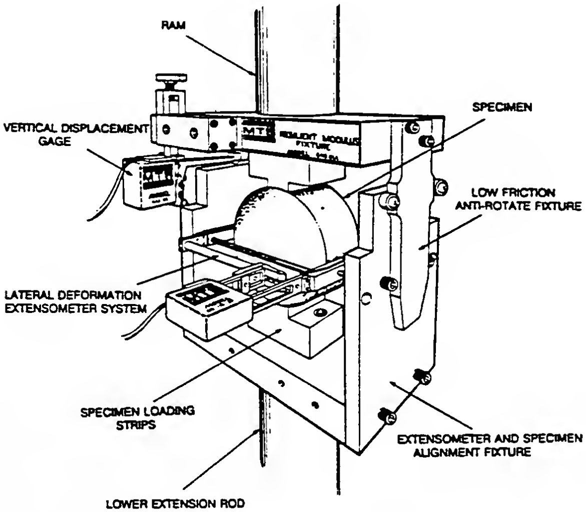


Figure 5.10 Installation of Specimen for Resilient Modulus Testing
(After MTS Manual, 1994)

5.7 Hamburg Wheel Tracking Device

5.7.1 Background and Equipment

Hamburg Wheel Tracking was introduced to the United States in 1990 after the representatives of the American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), National Asphalt Pavement Association (NAPA), Strategic Highway Research Program (SHRP), Asphalt Institute (AI) and Transportation Research Board (TRB) made a two week research tour of six European countries. (Aschenbrener, 1993).

It is reported that the Hamburg Wheel Tracking Device has been used in the Hamburg, Germany vicinity since 1974. This device was used as a research tool for binder course mixture. In 1984, the Hamburg Road Authority began to use wheel tracking tests as a specification tool (Elf Industries, 1992). This device was developed to measure moisture damage and resistance to permanent deformation due to a high volume of truck traffic near the city of Hamburg shipping dock area. (Habermann, 1994). After the European pavement study tour, the Colorado Department of Transportation (CDOT) and the FHWA Turner-Fairbank Highway Research Center demonstrated the Hamburg Wheel Tracking Device in the United States (Aschenbrener, 1993). The Hamburg Wheel Tracking Device used in this study was purchased in May, 1990 from Helmut Wind Inc. of Hamburg, Germany by Koch Materials, Terre Haute, Indiana.

As discussed above, the Hamburg wheel tracking device can be used to measure permanent deformation and stripping potential. The Hamburg wheel tracking device has

been recently used in the United State as a potential stripping test (Aschenbrener, 1993). Figure 5.11 show a schematic diagram of the Hamburg wheel tracking device.

5.7.2 Preparation and compaction of sample slabs

The same mix preparation procedures performed in the Marshall method were used for mix preparation in the Hamburg wheel tracking device. The difference is that large amounts of materials were used. A total of 8600 grams of aggregate was needed for one sample slab. Duplicate slabs were prepared for each mixture.

Based on results from the Gyratory Testing Machine, the selected mixtures prepared were, 10 % and 15 % CB and PCB mixtures, since both 10% and 15 % mixtures showed better performance than other percentages of mixtures. Therefore, 10 sets of mixtures, and a total of 20 sample slabs were tested with the Hamburg wheel tracking device.

A linear kneading compactor was used for the preparation of sample slabs at 6 percent target air voids. The kneading action provides the desired density without fracturing aggregates in the mixture. Consistent specimens can be produced by the compactor. Consider also that the linear kneading compactor produces a linear compression wave in the mix so that it simulates roller operation occurring in the field. The size of sample slab is 320 mm (12.6 in.) long, 260 mm (10.2 in.) wide, and 40 mm (1.6 in.) deep. Figure 5.12 shows the linear kneading compactor diagram. The prepared sample slabs were measured for bulk specific gravity according to ASTM D2726. Table 5.3 shows the condition of sample slabs for the Hamburg wheel tracking device.

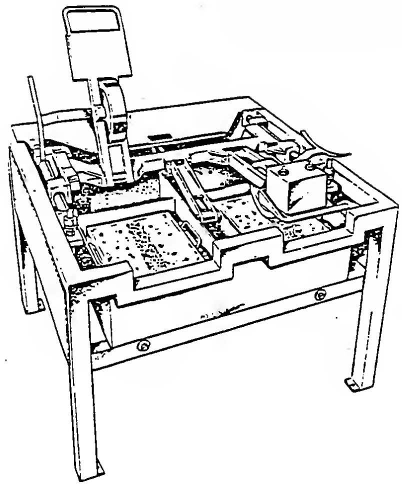


Figure 5.11 Hamburg Wheel Tracking Device (After Elf Industries, 1992)

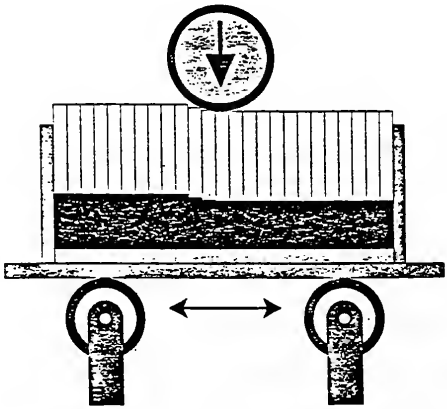


Figure 5.12 The Linear Kneading Compactor Diagram (After Elf Industries, 1992)

Table 5.3 The Condition of Sample Slabs for Hamburg Wheel Tracking Device

Mix Type	Bulk S.G.	Theoretical Max. S.G.	Air Voids (%)	Height of Slab(in.)
AC-10	2.455	2.576	4.7	1.503
AC10+10%CB	2.455	2.576	4.7	1.504
AC10+15%CB	2.455	2.580	4.8	1.504
AC10+10%PCB	2.448	2.568	4.7	1.506
AC10+15%PCB	2.443	2.568	4.9	1.508
AC-20	2.442	2.510	2.7	1.507
AC20+10%CB	2.441	2.571	5.1	1.503
AC20+15%CB	2.432	2.568	5.3	1.503
AC20+10%PCB	2.470	2.575	4.1	1.504
AC20+15%PCB	2.564	2.449	4.5	1.503

5.7.3 Testing Procedures

The prepared sample slabs were completely immersed in water at 122°F (50°C) for 30 minutes in order to ensure thermal stability. The wheels were placed on the sample slabs and started in motion. The deformation of the mixtures were captured by an LVDT, and the data acquisition system started to record the test results. The data recorded by the acquisition system are ; 1) the numbers of passes of the wheel; 2) a) deformation of slab 1 and slab 2; b) comparison of deformation of slab 1 and that of slab 2; 3) average deformation; 4) the water temperature (°C).

The principal sketch of the Hamburg wheel tracking device is illustrated in Figure 5.13. Following the information provided by Koch Material, sample slabs were tested under 204 mm (8 in.) diameter, 47 mm (1.85 in.) wide flat steel wheels. The wheel reciprocates sinusoidally at a velocity of 1.4 cm/sec. The wheel provides 71 kg (160 lb) loads to the sample slabs during the test. This test protocol provides cycles of approximately 0.1 second loading and 0.9 second rest. The vertical deformation of sample slabs is measured by an LVDT at the center of the sample slabs to the nearest 0.01 millimeter. Each sample slab is subjected 20,000 passes of the wheel or until 20 millimeter of deformation occurs. The test is ended when either condition is achieved.

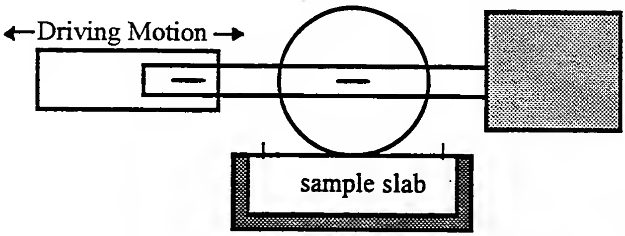


Figure 5.13 The Principal Sketch for Hamburg Wheel Tracking Device

5.8 Indirect Tensile Testing

5.8.1 Background and Equipment

The indirect tensile test provides two mixture properties that are useful in characterizing hot mixed asphalt. The first property is tensile strength, which is often used in evaluating water susceptibility of mixtures. The second property determined is tensile strain at failure. This is useful for predicting the cracking potential (Robert et al., 1991). The indirect tensile test was performed to determine the tensile strength at low temperature (5°C) in this study. The tensile strength at low temperature indicates the cracking potential of the mixture.

The 810 Material Testing System (MTS) was used, which is the same equipment used for creep testing and for the resilient modulus test. The apparatus for testing was originally designed for the resilient modulus test for asphalt mixtures in accordance with ASTM D4123.

5.8.2 Preparation of Specimens

After the creep test and the resilient modulus test were completed, the same specimens were used for indirect tensile tests. As mentioned previously, all specimens were prepared by the Marshall compactor with 6 percent target air voids.

The diametral setup was employed because, according Kim et al. (1991), the test procedure is relatively simple; failure is initiated in a region of relatively uniform tensile stress, and stress and strain solutions are readily available. Furthermore, the same specimens can be used after the creep test and the resilient modulus test. Figure 5.14

shows the schematic of the fixture used for this study. The fixture was installed inside of the environmental chamber with the temperature controlled.

5.8.3 Testing Protocol

A constant 1 second repeated loading cycle that contains haversine load with 0.1 second loading period and 0.9 second unloading period was applied to the sample for 50 seconds for the conditioning of the specimens. The compressive loading was applied to the conditioned specimens until failure occurred. The loading stroke rate of 0.5 in./min (13 mm/min was used in accordance with SHRP recommendation (SHRP-A-379, 1994). The data sampling frequency of 20 Hz was used.

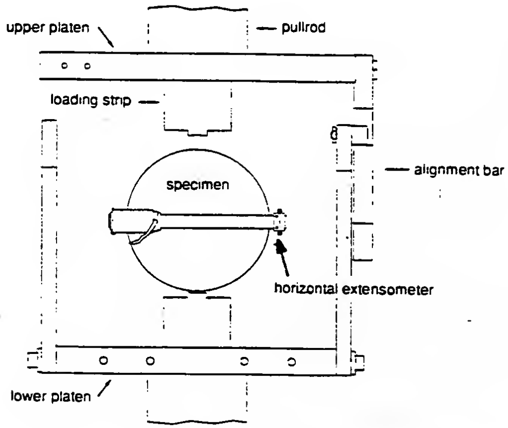


Figure 5.14 Schematic of Diametral Indirect Tensile Testing Setup (After MTS Manual, 1994)

CHAPTER 6

PRESENTATION OF TESTS RESULTS AND DISCUSSION

6.1 Introduction

After the completion of the laboratory testing program, the test data were analyzed to evaluate the effectiveness of the PCB in AC-10 and AC-20 mixtures. Relative comparisons were made to CB modified asphalt concrete and to conventional asphalt concrete. The mechanical properties of the PCB mixtures were evaluated by the Marshall method. The Marshall stability and flow were measured. The stress-strain relationship of the PCB mixture was obtained through the use of the Gyratory Testing Machine. The Dynamic Confined Creep Test provided information on the rutting resistance of the PCB mixtures. The strength and temperature susceptibility of the PCB mixtures were evaluated at both low and high temperature (5°C and 25°C) by the Resilient Modulus Test. The cracking potential of the PCB mixtures was evaluated and analyzed by the test results of the Indirect Tensile Test. In addition, the Hamburg Wheel Tracking Device was used to evaluate the stripping inflection point of the PCB mixtures. The test results and discussion are presented in the following sections.

6.2 Marshall Test Method

6.2.1 Test Results

The Marshall test results are used to define the characteristics of bituminous mixtures in relation to their binder content. Two parameters were determined from the Marshall results in this study. The optimum binder content was determined and the stability and flow were used to provide a measure of the strength of mixtures. Compacted samples were tested and the test data compared as follows:

1) Bulk Specific Gravity vs. Binder Content

2) Air Voids(%) vs. Binder Content

3) VMA(%) vs. Binder Content

4) VFA(%) vs. Binder Content

5) Stability vs. Binder Content

6) Flow vs. Binder Content

While the Marshall test method of asphalt mixtures is standardized (ASTM D1559), the criteria of acceptance vary from state to state. The INDOT criteria were adopted to determine the optimum binder content, as shown in Table 6.1. These optimum binder contents were compared to the U.S. Army criteria(Table 6.2) and the Asphalt Institute criteria(Table 6.3).

It is interesting to compare the Marshall criteria for each agency. The INDOT specifies only one compaction level, however, the Asphalt Institute specifies three different levels of compaction. The criterion of the Marshal stability and VMA varies for each

agency also. The most important criterion is the air void range. The INDOT requires between 5 and 6 percent, the U.S. Army 4 to 6 percent for a binder course, and the Asphalt Institute 3 to 5 percent. Compared to other variables, the air voids is most closely related with the determination of the optimum binder content. Figures 6.1 through 6.17 illustrate the test data for each mixture. These Figures show that those mixtures containing PCB and CB are less consistent than AC-10 and AC-20 mixtures. Inclusion of PCB and CB may account for this variability. All test data by the Marshall method such as bulk specific gravity and maximum theoretical specific gravity test results are provided in Appendix B and Appendix C, respectively. A summary of the Marshall test results and mixture properties is also provided in Appendix D. Values which are obviously in error were not included in the average.

Table 6.1 INDOT Marshall Criteria

MIX CRITERIA	MIN.	MAX.
Compaction (No. of blows each side of specimen)	75	75
Stability (lb.)	1200	-
Flow	6	16
Percent Air Voids	4.0	8.0
Percent Voids in Mineral Aggregate (VMA)		
• 3/8"(9.5 mm) Nominal Maximum Particle Size	16	-
• 1/2" (12.5 mm) Nominal Maximum Particle Size	15	-
• 3/4" (19.0 mm) Nominal Maximum Particle Size	14	-
• 1" (25.0 mm) Nominal Maximum Particle Size	13	-
Base 5D Mixture	12	-

Note 1)The nominal maximum particle size is the largest sieve upon which any material will be permitted to be retained.
2)The percent air voids for base 5D mixture shall be 3.0 to 5.0.
3) The optimum bitumen content shall be the bitumen content that procedures 6.0 percent air voids for all mixtures except base 5D [401.04(b)]

Table 6.2 U.S Army Marshall Criteria (After U.S. Army TM 5-822-8, 1987)

Test Property	Type of Mix	Criteria for 100 psi tires
Stability	All*	Min. 500 lb.
Unit Weight		Not Used
Flow	All*	Max. 20
% Voids Total Mix	Asphalt Concrete	3 - 5
	Sand Asphalt	5 - 7
	Binders	4 - 6
% Aggregate Voids Filled	Asphaltic Concrete	75 - 85
	Sand Asphalt	65 - 75
	Binder	65 - 75

* Asphaltic concrete, sand asphalt, and binders.
Note : The criteria shown above for 100 psi tires are often used in the design of highway pavements, but they are subject to modification where substantial experience indicates the need for such a change.

Table 6.3 Marshall Mix Design Criteria for Asphalt Institute (After MS-2, 1994)

Marshall Method Mix Criteria 1	Light Traffic Surface & Base Min	Light Traffic Surface & Base Max	Medium Traffic Surface & Base Min	Medium Traffic Surface & Base Max	Heavy Traffic Surface & Base Min	Heavy Traffic Surface & Base Max
Compaction, number of blows each end of specimen	35		50		75	
Stability, N (lb.)	3336 (750)	—	5338 (1200)	—	8006 (1800)	—
Flow, 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)	***See below table (Minimum percent voids in mineral aggregate)***					
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

NOTES
1. All criteria, not just stability value alone, must be considered in designing an asphalt paving mix. Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
2. Traffic classifications
   - Light Traffic conditions resulting in a Design EAL $<10^4$
   - Medium Traffic conditions resulting in a Design EAL between 10^4 and 10^6
   - Heavy Traffic conditions resulting in a Design EAL $>10^6$
3. Laboratory compaction efforts should closely approach the maximum density obtained in the pavement under traffic.
4. The flow value refers to the point where the load begins to decrease.
5. The portion of asphalt cement lost by absorption into the aggregate particles must be allowed for when calculating percent air voids.
6. Percent voids in the mineral aggregate is to be calculated on the basis of the ASTM bulk specific gravity for the aggregate.

Minimum percent voids in mineral aggregate (VMA)

Nominal Maximum Particle Size[1, 2] mm	in.	Minimum VMA, percent — Design Air Voids, Percent[3] 3.0	4.0	5.0
1.18	No. 16	21.5	22.5	23.5
2.36	No. 8	19.0	20.0	21.0
4.75	No. 4	16.0	17.0	18.0
9.5	3/8	14.0	15.0	16.0
12.5	1/2	13.0	14.0	15.0
19.0	3/4	12.0	13.0	14.0
25.0	1.0	11.0	12.0	13.0
37.5	1.5	10.0	11.0	12.0
50	2.0	9.5	10.5	11.5
63	2.5	9.0	10.0	11.0

1 - Standard Specification for Wire Cloth Sieves for Testing Purposes, ASTM E11 (AASHTO M92)
2 - The nominal maximum particle size is one size larger than the first sieve to retain more than 10 percent.
3 - Interpolate minimum voids in the mineral aggregate (VMA) for design air void values between those listed.

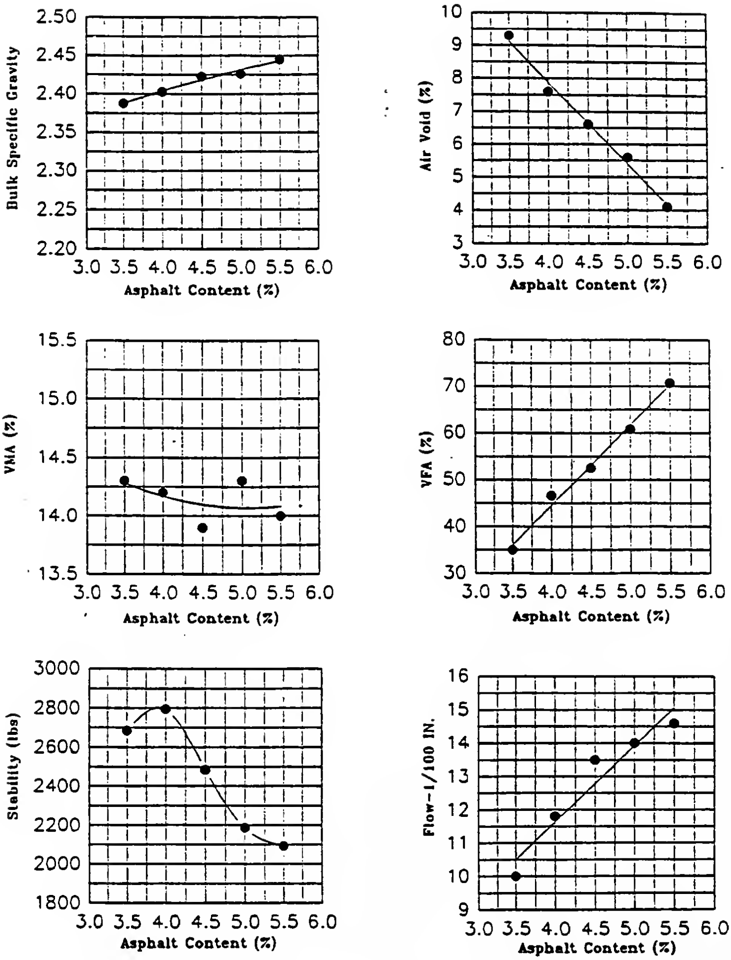


Figure 6.1 Graphical Summary of Test Data by Marshall Method (AC-10)

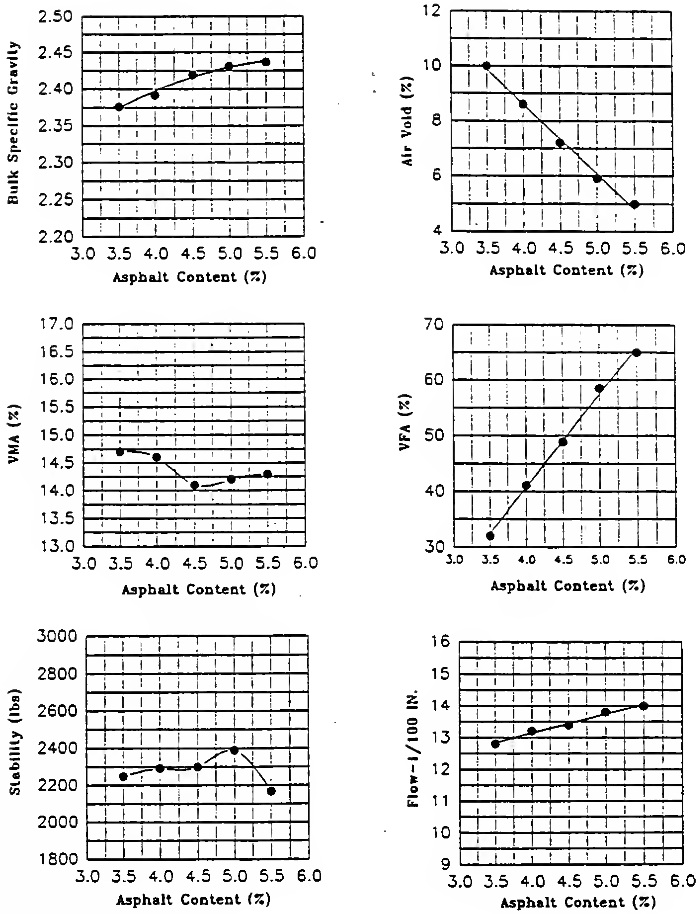


Figure 6.2 Graphical Summary of Test Data by Marshall Method (AC10+5%CB)

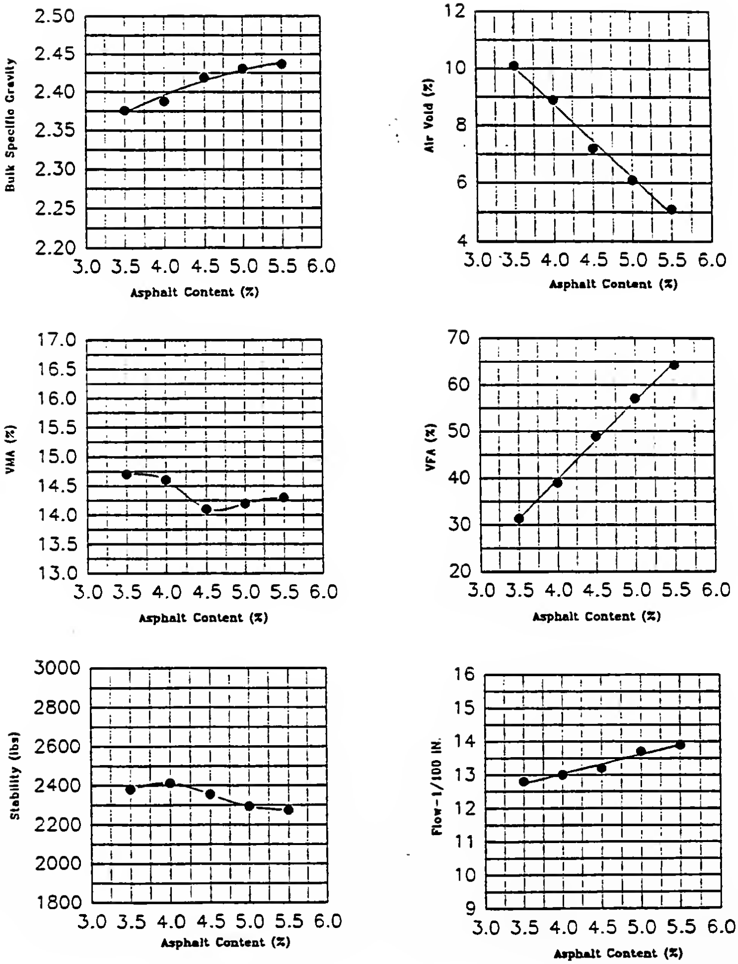


Figure 6.3 Graphical Summary of Test Data by Marshall Method (AC10+10%CB)

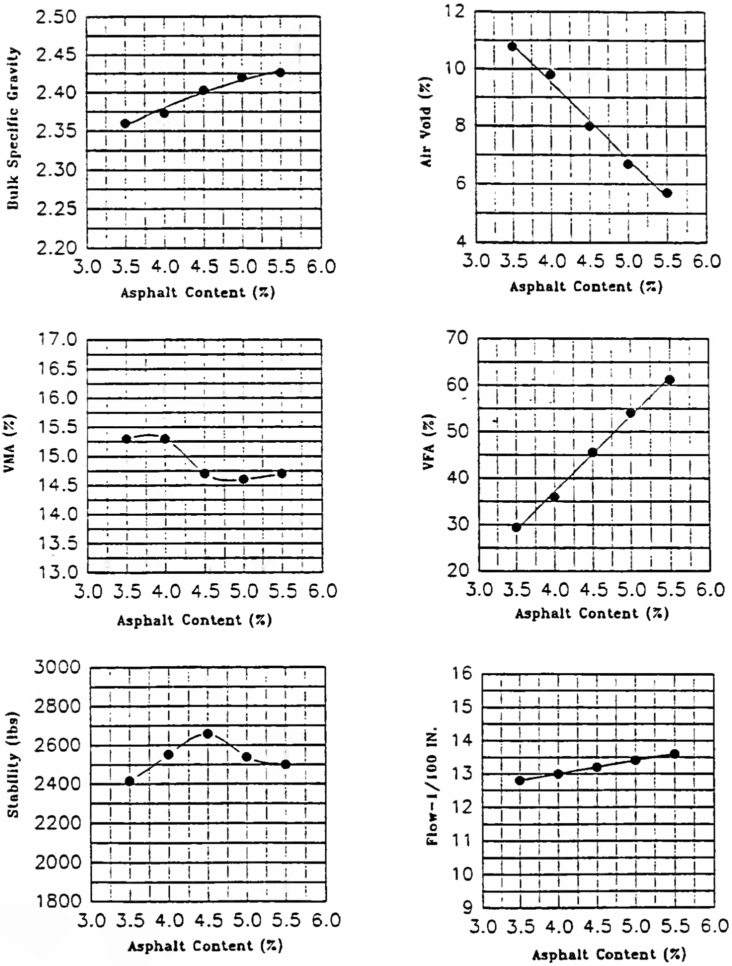


Figure 6.4 Graphical Summary of Test Data by Marshall Method (AC10+15%CB)

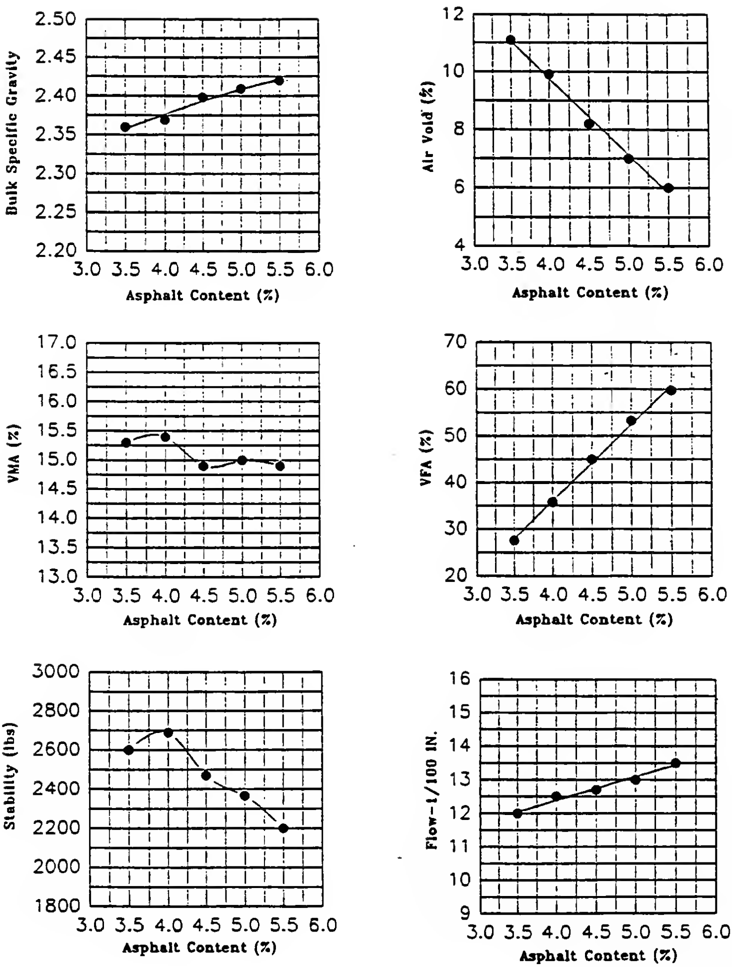


Figure 6.5 Graphical Summary of Test Data by Marshall Method (AC10+20%CB)

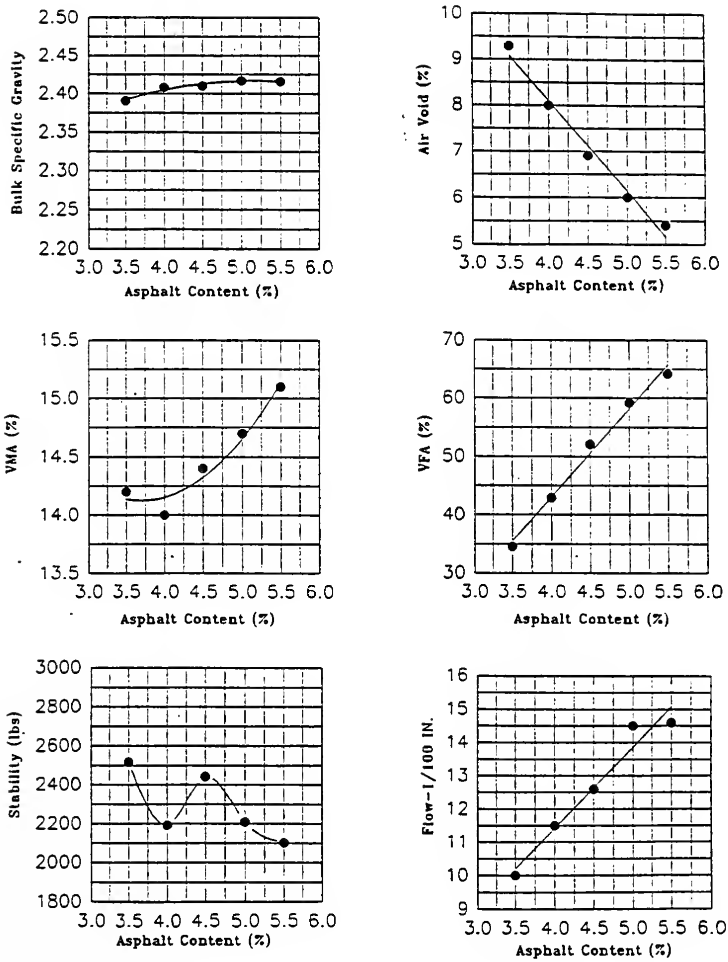


Figure 6.6 Graphical Summary of Test Data by Marshall Method (AC10+5%PCB)

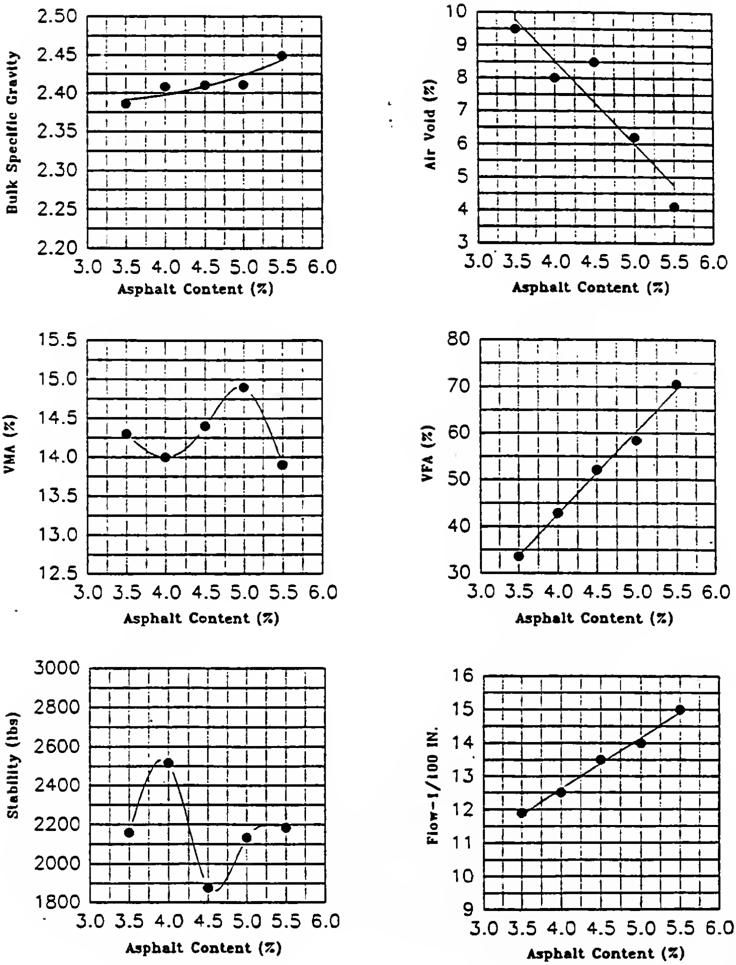


Figure 6.7 Graphical Summary of Test Data by Marshall Method (AC10+10%PCB)

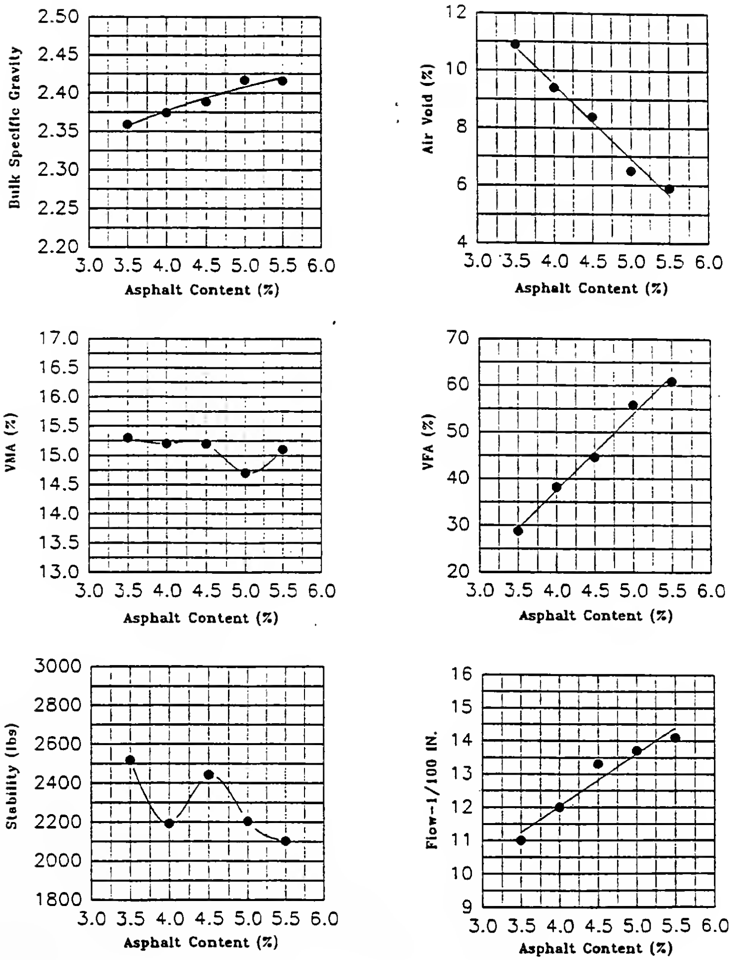


Figure 6.8 Graphical Summary of Test Data by Marshall Method (AC10+15%PCB)

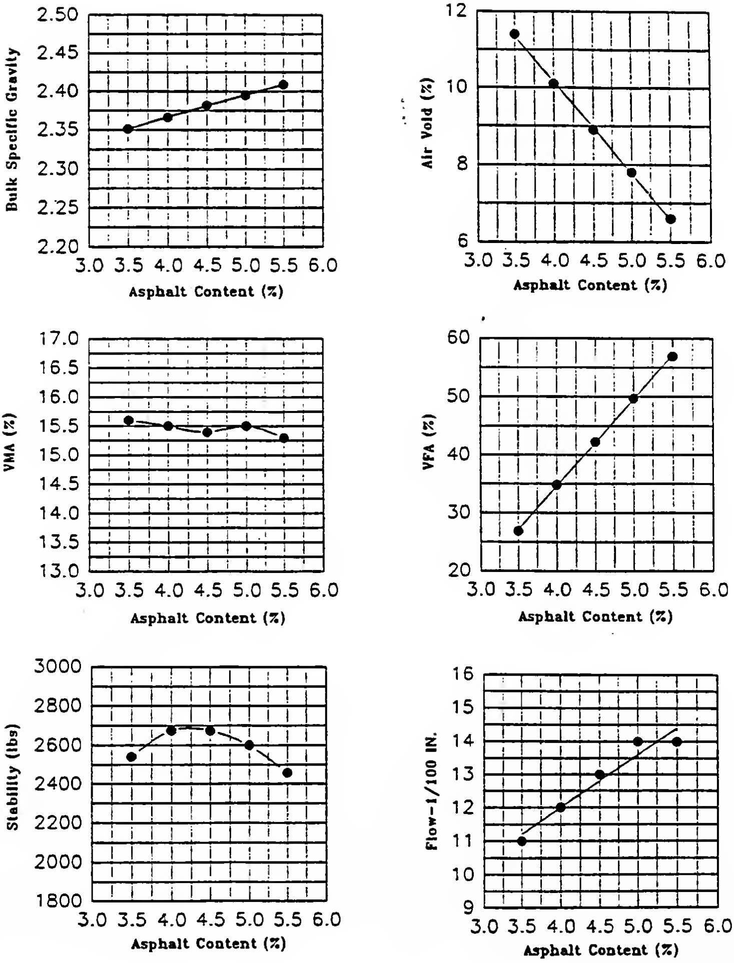


Figure 6.9 Graphical Summary of Test Data by Marshall Method (AC10+20%PCB)

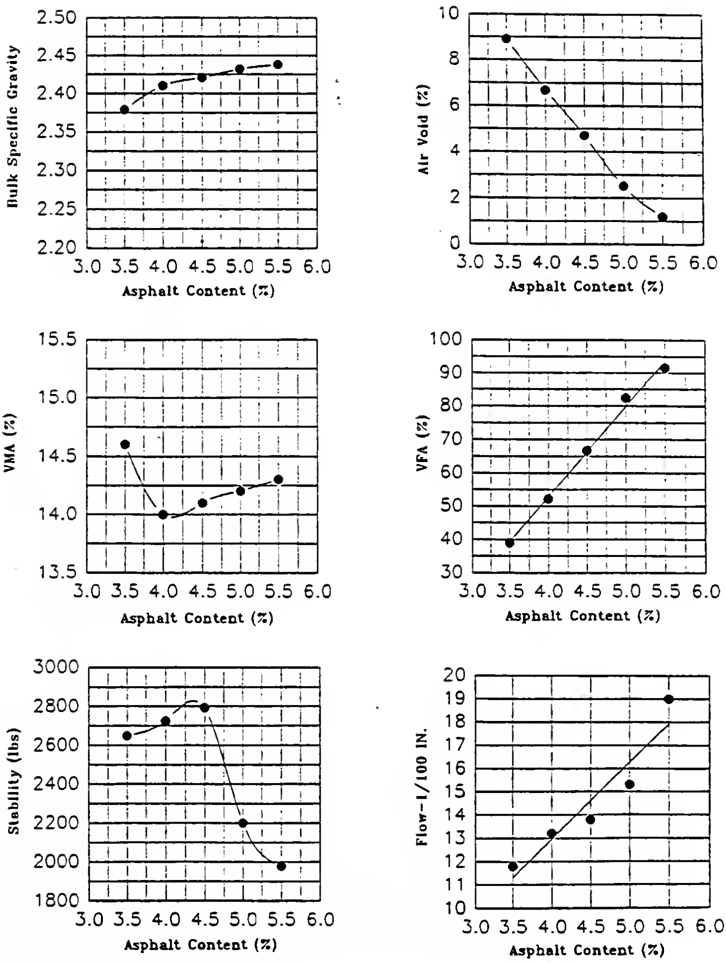


Figure 6.10 Graphical Summary of Test Data by Marshall Method (AC-20)

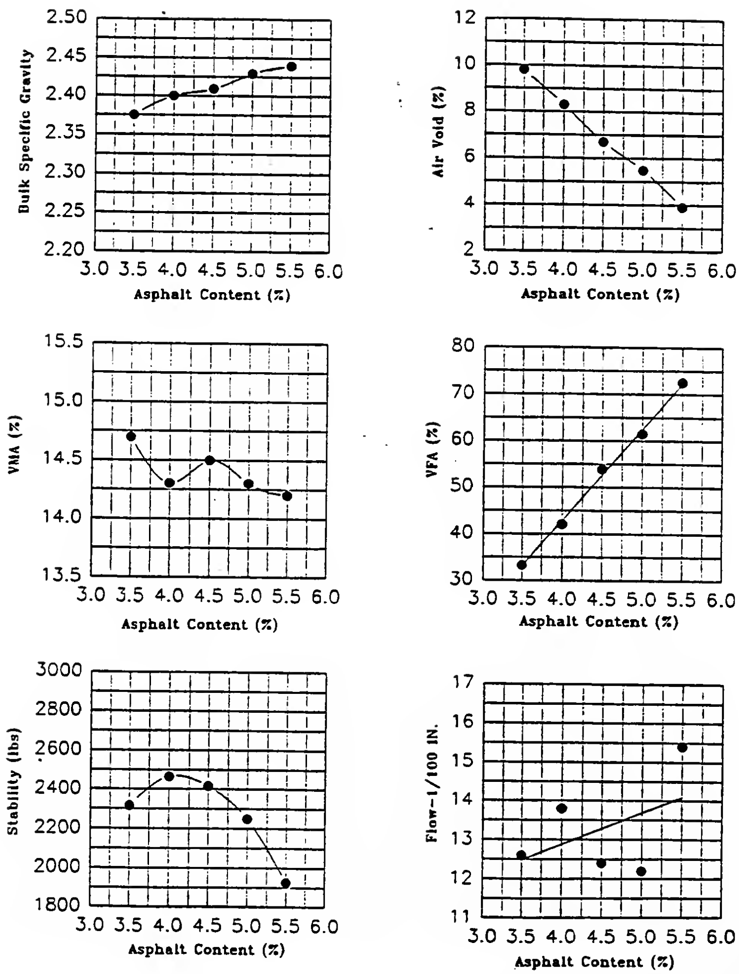


Figure 6.11 Graphical Summary of Test Data by Marshall Method (AC20+5%PCB)

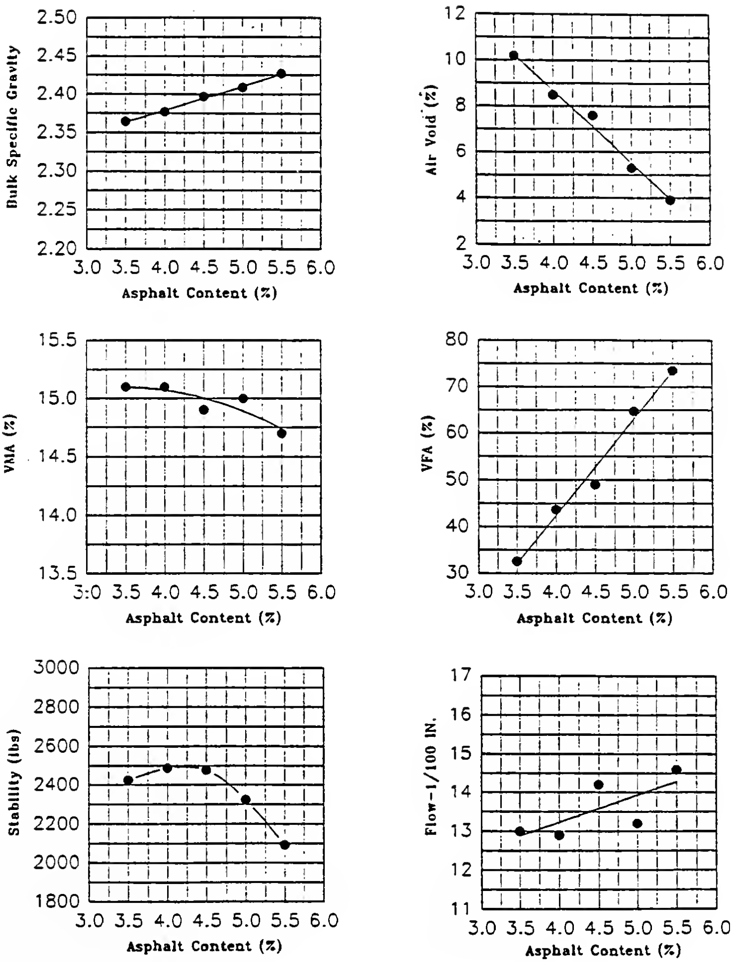


Figure 6.12 Graphical Summary of Test Data by Marshall Method (AC20+10%PCB)

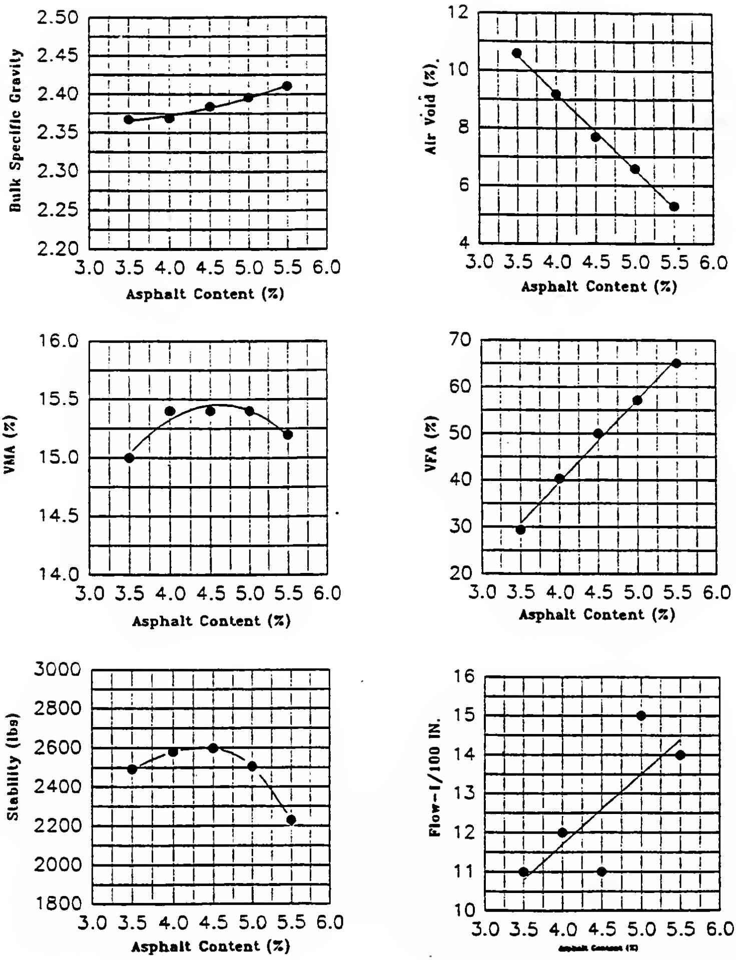


Figure 6.13 Graphical Summary of Test Data by Marshall Method (AC20+15%PCB)

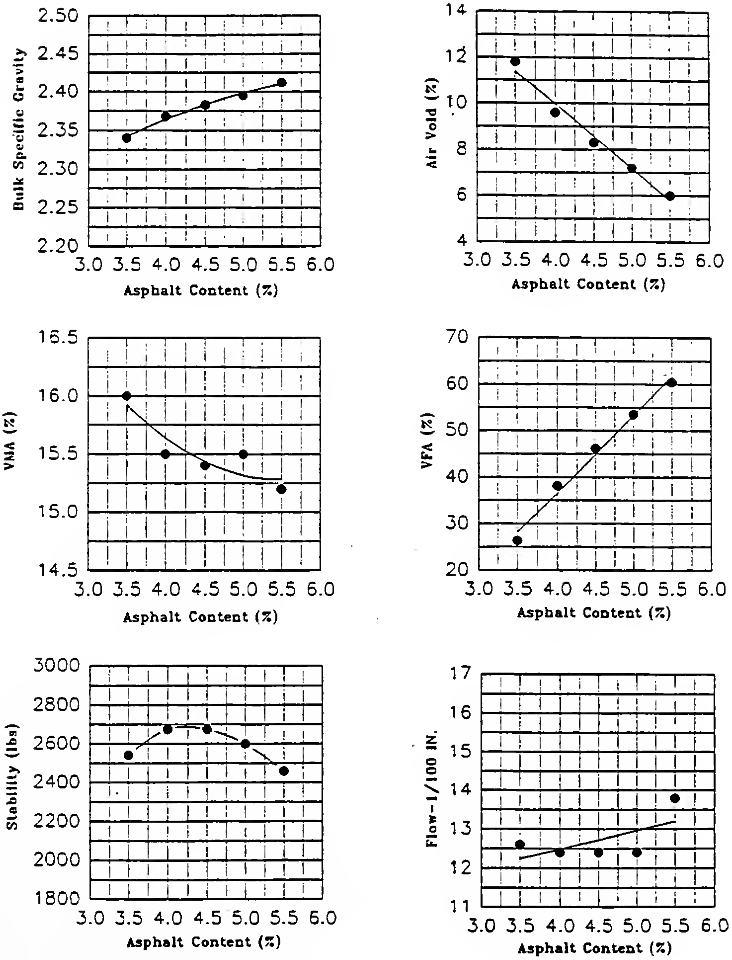


Figure 6.14 Graphical Summary of Test Data by Marshall Method (AC20+20%PCB)

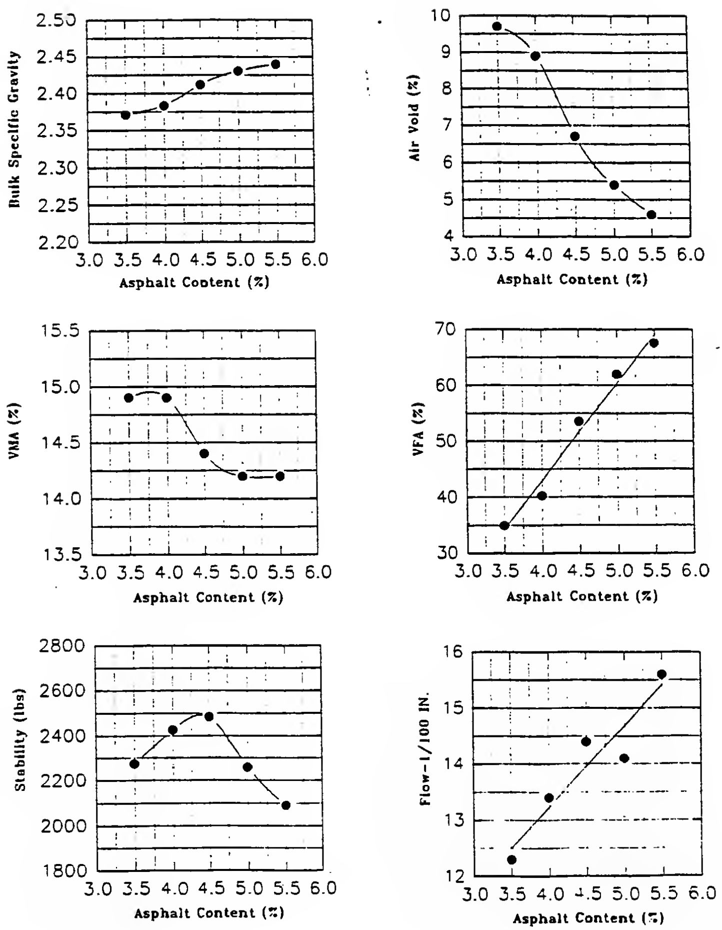


Figure 6.15 Graphical Summary of Test Data by Marshall Method (AC20+10%CB)

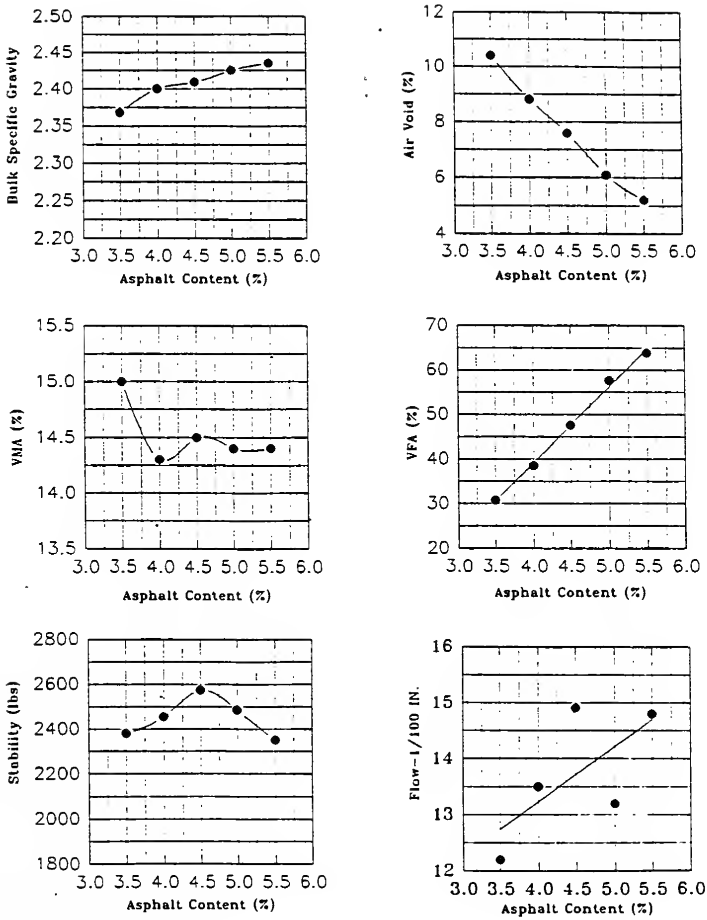


Figure 6.16 Graphical Summary of Test Data by Marshall Method (AC20+15%CB)

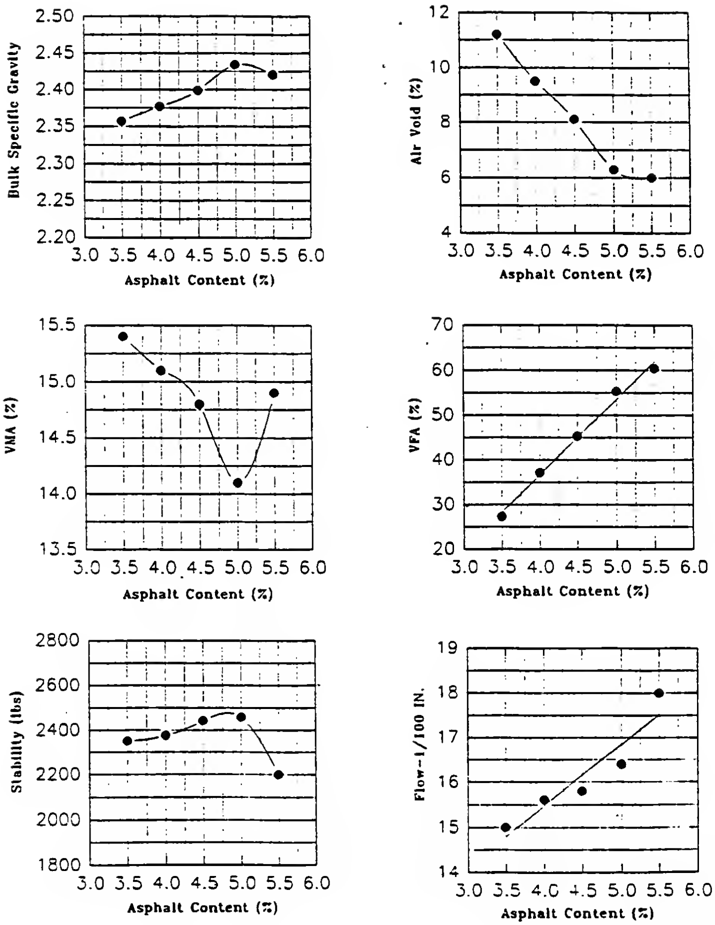


Figure 6.17 Graphical Summary of Test Data by Marshall Method (AC20+20%CB)

6.2.2 Air Voids

The air voids, voids in total mix (VTM), are estimated by comparing the average bulk specific gravity (*Gmb*) to the theoretical maximum specific gravity (*Gmm*) at each asphalt content. The air voids can be calculated by the following relationship:

$$\text{VTM} = \left(1 - \frac{G_{mb}}{G_{mm}}\right)100 \qquad (6.1)$$

Where, G_{mb} = Bulk Specific Gravity

G_{mm} = Theoretical Maximum Specific Gravity

<u>Air voids vs. Carbon Black Contents</u>

Figure 6.18 and Figure 6.19 show the air voids vs. carbon black content for AC-10 and AC-20 binder mixtures. It is noted that the air voids increase as the carbon black content increases for both bitumen grades. This is a typical effect of inclusion of particulate additives in asphalt ; Khadaywi (1988) reported similar results on oil shale ash modified binder. The air voids decrease with increasing the binder content.

<u>Air Voids vs. PCB Content</u>

Figure 6.20 and Figure 6.21 show the relationship between the air voids and the PCB content for both bitumen grades. The general trend is the same as for CB mixtures. The air voids increase almost linearly with increasing PCB contents. Significant changes were not observed in the general trend when comparing the conventional mixture and the CB mixture.

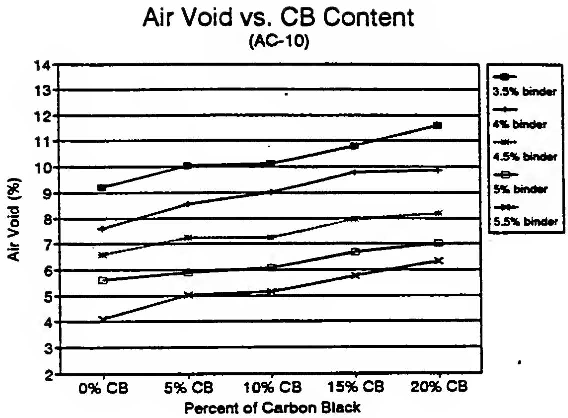


Figure 6.18 Air Voids vs. Carbon Black Contents (AC-10)

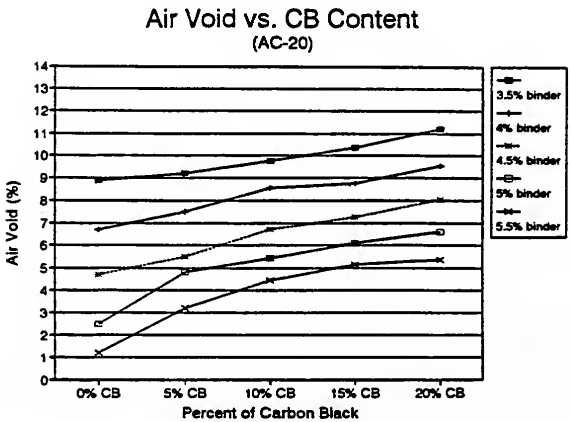


Figure 6.19 Air Voids vs. Carbon Black Contents (AC-20)

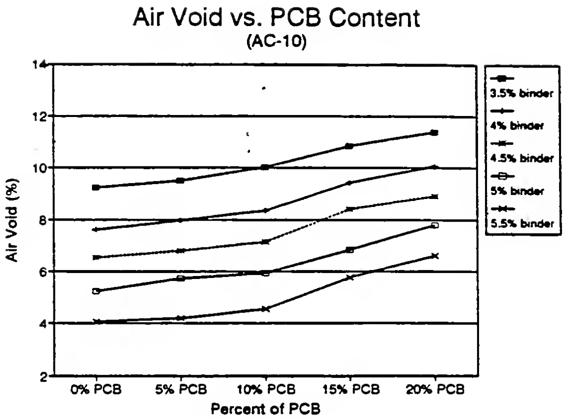


Figure 6.20 Air Voids vs. PCB Contents (AC-10)

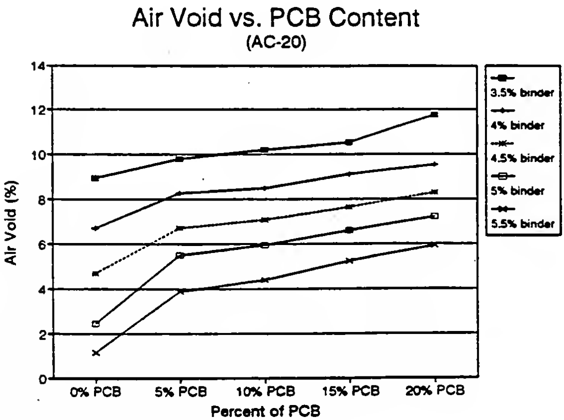


Figure 6.21 Air Voids vs. PCB Contents (AC-20)

The air voids in the asphalt mixtures is an important factor because their physical properties and performance, such as stability and durability, are directly influenced by air voids (Brown and Cross, 1989; Ford, 1988).

It is reported that rutting is likely to occur due to plastic flow when the in-place air voids decrease to less than 3 percent (Brown and Cross, 1989, Ford 1988, Huber and Herman, 1987). When the air voids are higher than 8 percent, the mixtures are likely to be damaged by the penetration of water and air. Therefore, the mixtures become susceptible to be damaged by water and air, as the rate of oxidation of the binder is significantly increased and accelerated. In this case, the oxidation rate of the mixtures is increased so that premature cracking can occur (Zube 1962, Brown et al. 1989, Santucci et al. 1985).

The relationship between air voids and stability was examined in this study in order to evaluate the sensitivity of each mixture to air void content. Figure 6.22 and Figure 6.23 present the relationship between corrected stability and air void content. These Figures show that both modified mixtures are less sensitive to binder content than unmodified mixtures. On the other hand, it appears that AC-20 mixtures show less sensitivity than AC-10 mixtures.

The pyrolized carbon black mixture shows less sensitivity to air void content and has marginally higher strength (stability) than CB mixtures. It can be inferred from these results that the inclusion of PCB into the soft asphalt (AC-10) contributed to an increase in stability and to a decrease in sensitivity of the stability in the hardened asphalt (AC-20).

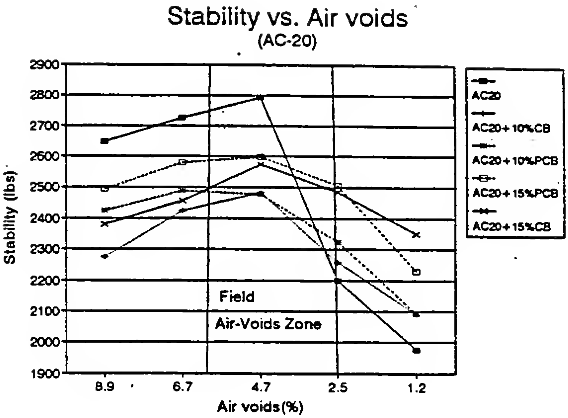


Figure 6.22 Air Voids vs. Stability (AC-20)

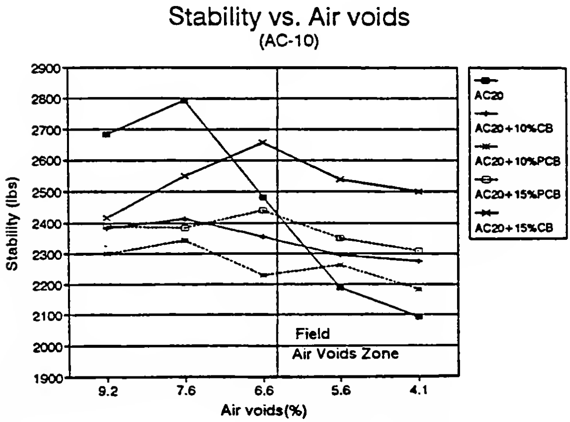


Figure 6.23 Air Voids vs. Stability (AC-10)

In accordance with the general relationship between air voids and Marshall stability, mixtures containing PCB modified binders may be expected to exhibit higher durability, strength, and retarded plastic deformation under traffic.

6.2.3 Voids in Mineral Aggregate

The VMA should be neither too low nor too high. If the VMA is too low, a satisfactory asphalt film thickness can not be provided. On the other hand, if the VMA is too high, the stability of the mixture can be reduced (Robert et al., 1991) The voids in mineral aggregate (VMA) are calculated from the following relationship.

$$\text{VMA} = 100\left[1 - \frac{G_{mb}(1-P_b)}{G_{sb}}\right] \tag{6.2}$$

where, G_{mb} : Bulk specific gravity of specimen

P_b : Binder content

G_{sb} : Bulk specific gravity of aggregate

<u>VMA vs. CB Contents</u>

The effects of carbon black in AC-10 mixtures and AC-20 mixtures are almost identical. Voids in mineral aggregate increase as the percent of carbon black increases and binder content decreases. Figure 6.24 and 6.25 show the variation of VMA for AC-10 and AC-20 by inclusion of carbon black.

<u>VMA vs. PCB Contents</u>

Figure 6.26 and Figure 6.27 show the effects of the VMA by the inclusion of PCB in AC-10 mixtures and AC-20 mixtures, respectively. A general trend is not maintained for

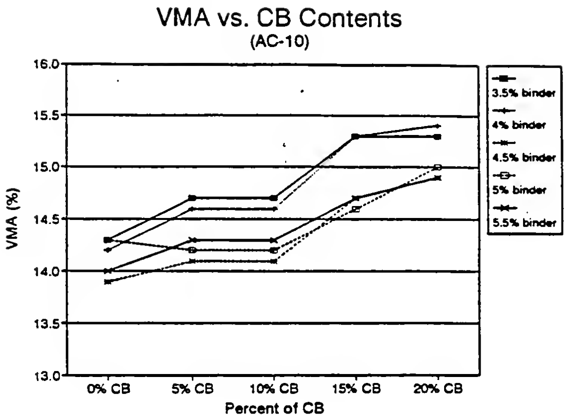


Figure 6.24 VMA vs. Carbon Black Contents (AC-10)

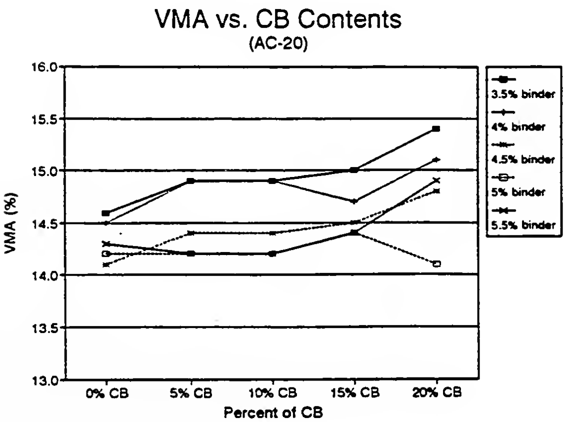


Figure 6.25 VMA vs. Carbon Black Contents (AC-20)

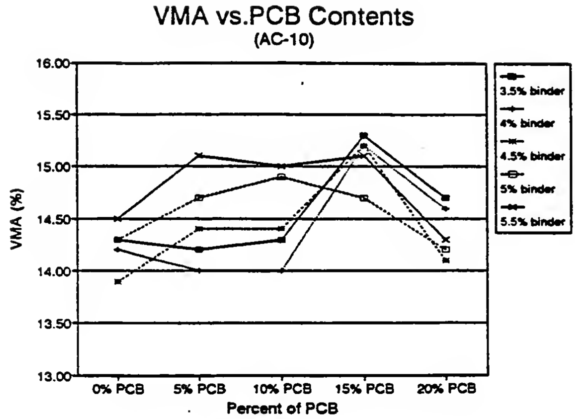


Figure 6.26 VMA vs. Pyrolized Carbon Black Contents (AC-10)

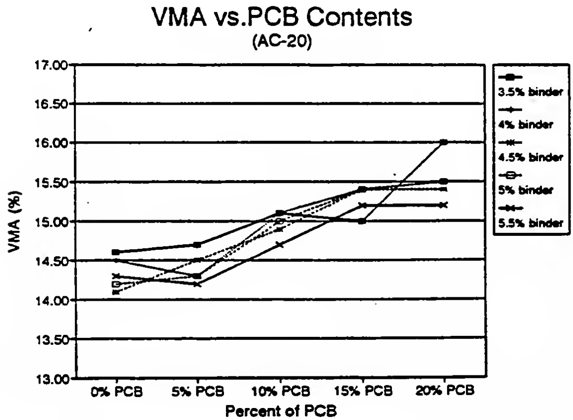


Figure 6.27 VMA vs. Pyrolized Carbon Black Contents (AC-20)

the inclusion of PCB in AC-10 mixtures. A particular trend observation is that high PCB (20 %) mixtures showed a sudden decrease of the VMA.

The AC-20 PCB mixtures show different trends, that is VMA is slightly higher than CB mixtures, and increase of the VMA is significant with increasing PCB content.

It is well known that the aggregate gradation, surface texture and shape are directly related to the VMA. Therefore, it can be inferred from the test result that PCB in the mixture may contribute to a denser gradation and rougher surface condition.

6.2.4 Voids Filled with Asphalt Cement

Voids filled with asphalt cement (VFA) is defined as the percentage of volume of voids in mineral aggregate filled with asphalt cement. The VFA is an important parameter in the determination of the stability and the rutting of the asphalt mixture. It has been found that when the VFA is over 80 % to 85 %, the asphalt mixture becomes unstable and rutting is likely to occur (Robert et al., 1991). The following relationship defines the VFA :

$$\mathrm{VFA} = \left(\frac{VMA - VTM}{VMA} \right) 100 \qquad (6.3)$$

<u>VFA vs. Carbon Black Contents</u>

Figure 6.28 and 6.29 show the relationship between VFA and carbon black contents for AC-10 and AC-20 mixtures. Voids filled with asphalt consistently decrease as the percent of carbon black increases for AC-10 and AC-20 mixtures.

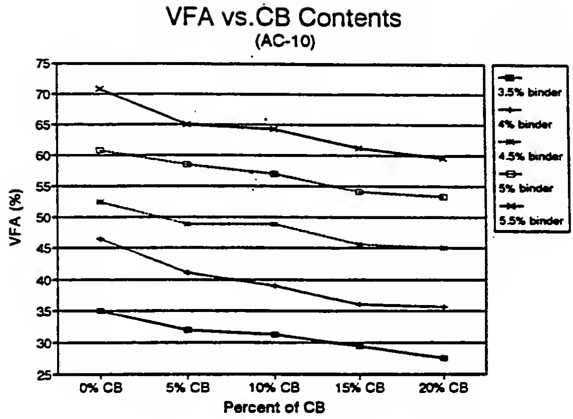


Figure 6.28 VFA vs. Carbon Black Contents (AC-10)

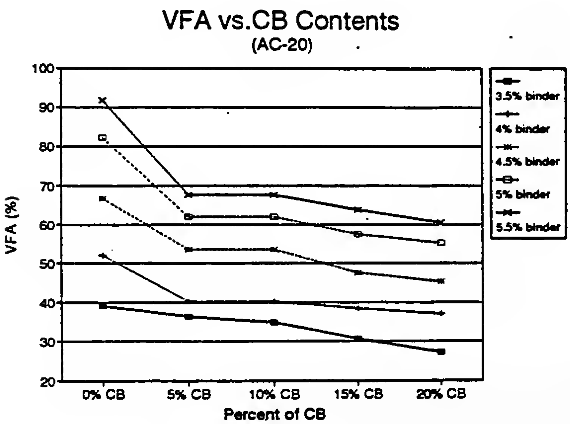


Figure 6.29 VFA vs. Carbon Black Contents (AC-20)

VFA vs. PCB Contents

Figure 6.30 and Figure 6.31 show test results for AC-10 PCB mixtures and AC-20 PCB mixtures. The AC-10 mixtures show relatively little change in VFA with increasing PCB content, reflecting the influence of VMA in the above equation.

6.2.5 Marshall Stability

The mechanical properties of the mixtures can be inferred from Marshall stability. The stability is the measure of the strength of the mixture. Marshall Stability has long been used to provide a laboratory estimate of the strength of the asphalt mixture.

Stability vs. CB Contents

The test results of stability vs. carbon black content for both grades of asphalt mixture do not appear to produce a specific trend. Figure 6.32 and Figure 6.33 show the relationship between stability and carbon black content for AC-10 and AC-20 mixtures. The test results show a maximum stability at a CB content of 15 percent, with the exception of lean mixtures using AC-10. The two lean mixtures (3.5 % and 4 %) showed an increasing stability through the range of CB contents tested.

Stability vs. PCB Contents

The AC-10 mixtures and the AC-20 mixtures show different responses due to the inclusion of PCB. The stability of AC-10 mixtures increases to 15 percent of PCB and then decreases; however, the stability of AC-20 mixtures increases with increasing of PCB content. Stability is roughly proportional to the PCB content for AC-20 mixtures.

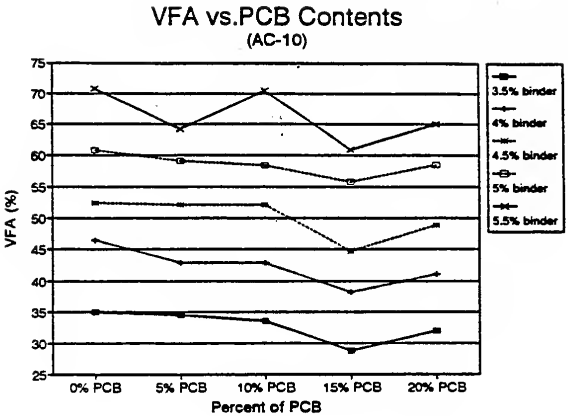


Figure 6.30 VFA vs. Pyrolized Carbon Black Contents (AC-10)

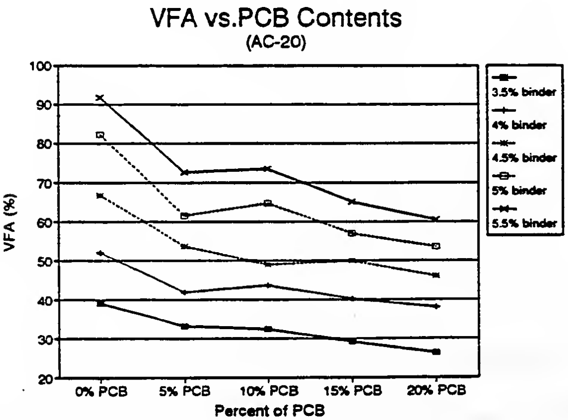


Figure 6.31 VFA vs. Pyrolized Carbon Black Contents (AC-20)

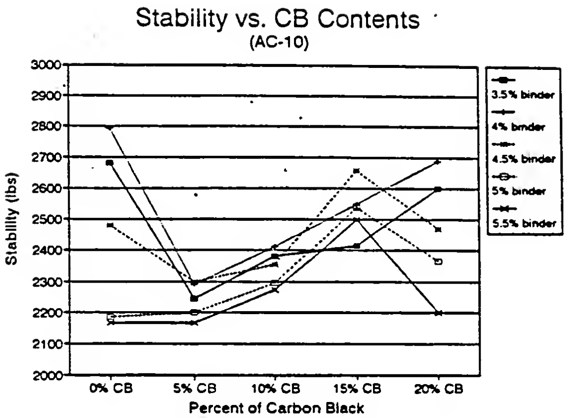


Figure 6.32 Stability vs. Carbon Black Contents (AC-10)

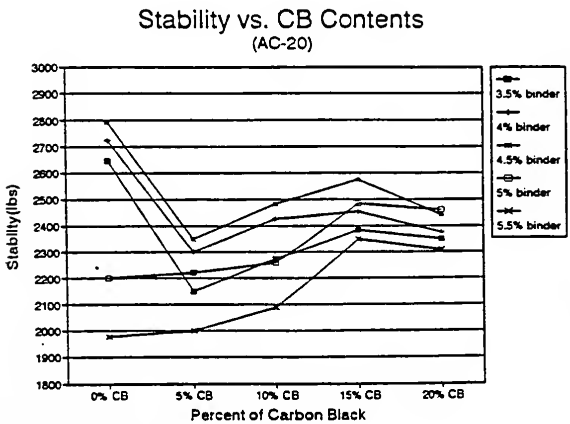


Figure 6.33 Stability vs. Carbon Black Contents (AC-20)

Figure 6.34 and Figure 6.35 show the relationships between stability and percent of PCB for AC-10 and AC-20 mixtures.

In general, PCB mixtures showed a reduction in stability at low PCB content levels. Although AC-10 PCB mixtures thereafter peaked at about 15 percent, they failed to achieve the stability of the conventional mixture. The AC-20 PCB mixtures also showed a loss of stability at low PCB content levels, but demonstrated a continuing increase with increasing PCB contents

6.2.6 Marshall Flow

Flow vs. Carbon Black Contents

Figure 6.36 and Figure 6. 37 show the effect of CB on Marshall flow for AC-10 and AC-20 mixtures. The flow increases with increasing carbon black content at lower binder content and then slightly decreases with increasing binder content for AC-10 mixtures. In AC-20 mixtures, the flow generally increases as carbon black contents increase. The increase rate of flow in AC-20 mixtures is much higher than in AC-10 mixtures.

Flow vs. PCB Contents

Figure 6.38 shows the flow test results for AC-10 PCB mixtures. Once again, the flow is essentially independent of PCB content in AC-10 mixtures. However, as shown in Figure 6.39, the AC-20 mixtures show a significant decrease in flow with increasing PCB content, indicating a potentially enhanced resistance to plastic flow.

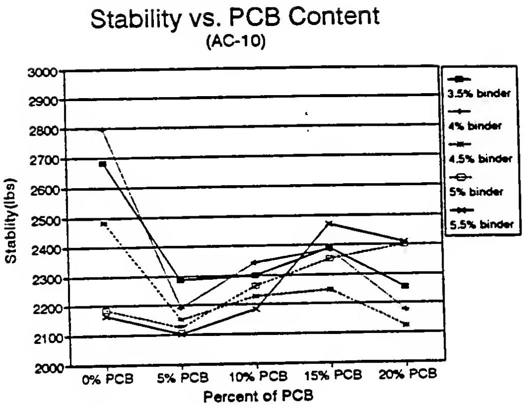


Figure 6.34 Stability vs. Pyrolized Carbon Black Contents (AC-10)

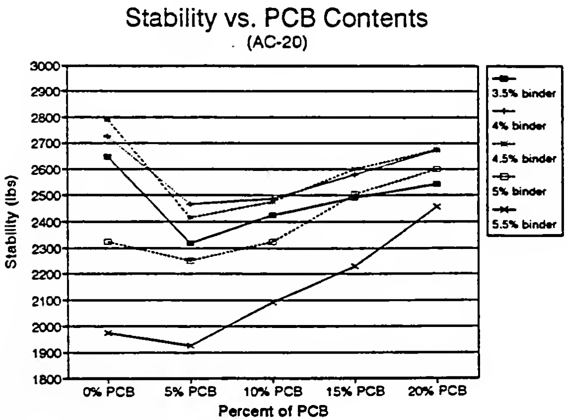


Figure 6.35 Stability vs. Pyrolized Carbon Black Contents (AC-20)

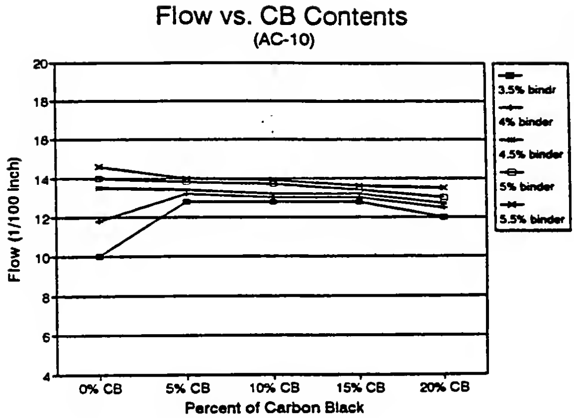


Figure 6.36 Flow vs. Carbon Black Contents (AC-10)

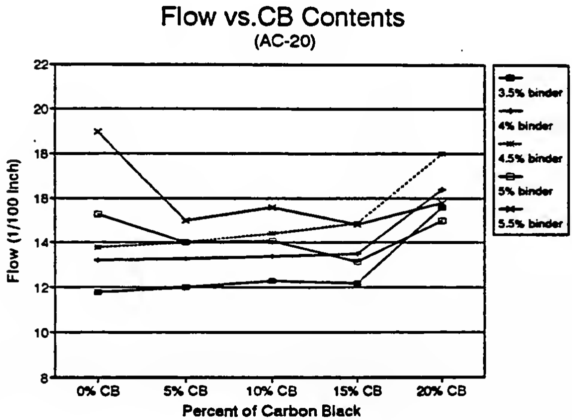


Figure 6.37 Flow vs. Carbon Black Contents (AC-20)

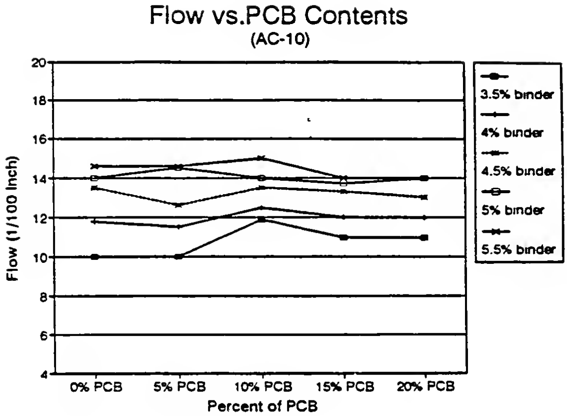


Figure 6.38 Flow vs. Pyrolized Carbon Black Contents (AC-10)

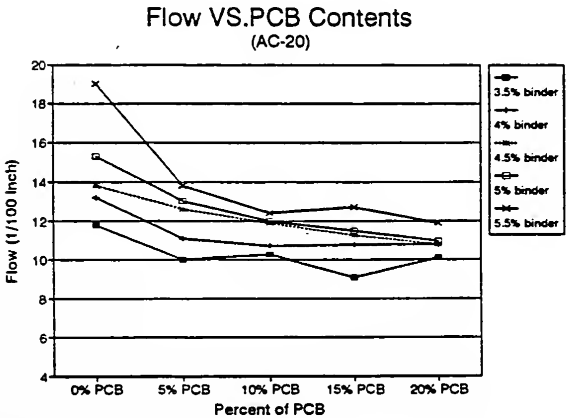


Figure 6.39 Flow vs. Pyrolized Carbon Black Contents (AC-20)

6.2.7 Optimum Binder Content

The optimum binder content is an important factor in asphalt pavement design, since it directly affects the capability of the asphalt pavement to support traffic load. The criteria for the determination of the optimum binder content criteria vary with each agency and state. The Indiana Department of Transportation (INDOT) criteria were used to determine the optimum binder content in this study. This optimum binder content was compared to the U.S. Army Corps Engineer and Asphalt Institute criteria in order to identify the differences of optimum binder content. Table 6.4 shows the optimum binder content for the three different criteria. As can be seen in Table 6.4, when the Asphalt Institute criteria are used, the optimum binder contents for AC-10 binder can not be defined. This reason is partly attributed to the increase of air voids when PCB and CB are blended with AC-10 asphalt. The air void increases with increasing CB and PCB contents. An identical trend was observed from AC-20 mixtures. An increase of asphalt content or control of the gradation might be required to satisfy the Asphalt Institute criteria. All of the mixtures began to bleed at binder contents greater than 5 percent in this study.

For AC-10 mixtures, when the U. S. Army Corps Engineers criteria were used to estimate the optimum binder contents, the criteria render slightly less optimum binder contents than when the INDOT criteria were used. However, for AC-20 mixtures, the INDOT criteria give greater optimum asphalt contents than the Asphalt Institue criteria. The determination of the optimum binder contents for each individual mixture are provided in Appendix E. It can be noticed from the plots that the general trend of the optimum binder contents increases with increasing the amount of the additives.

Figure 6.40 shows the comparison of the optimum binder contents. It can be seen that the optimum binder contents vary somewhat depending on the grade of the asphalt. Table 6.5 summarizes the effect of the inclusion of PCB and CB on the optimum binder contents for both grades of asphalt. The optimum asphalt contents decrease with increase of the PCB and CB content in AC-10 mixtures. Conversely the optimum binder contents increase in AC-20 binder with the inclusion of PCB and CB.

Table 6.4 The Optimum Binder Content of 3 Different Criteria

Agency	Asphalt	Pyrolized Carbon Black (%)					Carbon Black (%)			
		0	5	10	15	20	5	10	15	20
INDOT	AC-10	4.8	5.0	5.1	5.4	5.7	5.0	5.0	5.3	5.4
	AC-20	4.2	4.7	4.8	5.2	5.5	4.2	4.5	5.0	5.5
Asphalt Institute	AC-10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	AC-20	4.4 - 4.5	5.2 - 5.4	5.5	N/A	N/A	N/A	N/A	N/A	N/A
U.S Army	AC-10	4.7	4.9	5	5.2	5.5	5.2	4.9	5.2	5.2
	AC-20	4.3 - 4.4	4.7	4.75	5.1	5.2	4.8	4.9	5.1	5.2

Table 6.5 The Effect of PCB and CB in Optimum Binder Contents.

Asphalt	Pyrolized Carbon Black	Carbon Black
AC-10	Decrease	Decrease
AC-20	Increase	Increase

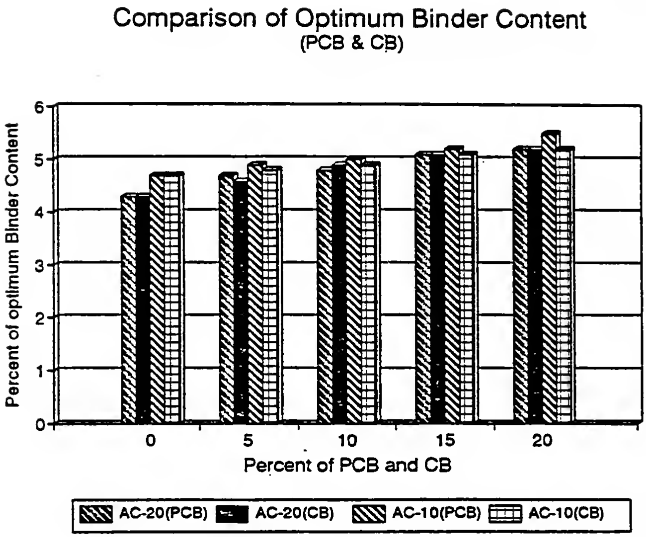


Figure 6.40 Comparison of Optimum Binder Contents

6.3 Gyratory Testing Machine

6.3.1 Test Results

The Gyratory Testing Machine (GTM) provides stress strain and plastic information. Test data and gyrographs are provided in Appendix F. The following information can be obtained from test data and gyrographs;

1) Air Voids vs. GTM Revolutions

2) Gyratory Compactibility Index (GCI)

3) Gyratory Stability Index (GSI)

4) Gyratory Shear (Sg)

5) Gyratory Shear Factor (GSF)

6) Gyratory Shear Modulus (Gg)

7) Gyratory Compression Modulus (Eg)

8) Unit Weight

6.3.2. Air Voids vs. GTM Revolutions

As mentioned in the Marshall Test Method, the air voids in the mixture is an important characteristic, since it permits the physical properties and performance of the mixture to be predicted for the service life of the pavement. The relationship between air voids and GTM revolutions for each mixture are illustrated in Figure 6.41, 6.42, 6.43 and 6.44. The acceptability of a PCB mixture can be determined from this relationship. The air void level of 5 to 8 percent after construction and that of 3 to 5 percent after traffic

densification have been found to be acceptable in most environments both for surface and for binder courses (Von Quintus et al., 1991).

As the GTM revolutions increase, air voids decrease as expected. Figure 6.41 and Figure 6.42 show the relationship between air voids and GTM revolutions for AC-10 CB mixtures and PCB mixtures, respectively. As can be seen from Figure 6.41, the rate of decrease of air voids for the CB mixtures is consistent with the increase of GTM revolutions and CB contents. The air voids decrease with increasing CB content. All CB mixtures contains more than 3 % air voids at 200 GTM revolutions. It is noted that as CB contents increase, the decrease in air voids become more significant.

However, as shown in Figure 6.42, the variation of air voids for the PCB mixture is not as significant as when the content of PCB is increased. It should be noted that when PCB content is greater than 10%, the variation of air voids is almost constant, ranging between 8 % and 3 %. From this it can be concluded that the variation of air voids is almost independent of the inclusion of PCB in this case.

Figure 6.43 and Figure 6.44 show the relationship between air voids and GTM revolutions for AC-20 CB mixtures and PCB mixtures, respectively. As shown in Figure 6.43, the CB mixtures experienced a constant decrease of air voids when both GTM revolutions and CB content were increased. The initial air voids of a conventional mixture is about 9 percent, and the final air voids is about 4 percent. Due to the microfiller action of carbon black, the percentage of air voids decreases with the increase of carbon black content. According to the test results, 5 % of carbon black showed an ideal behavior, but

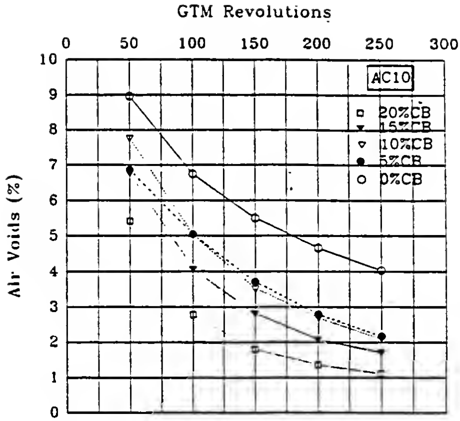


Figure 6.41 Relationship between Air Voids and GTM Revolutions (AC10+CB)

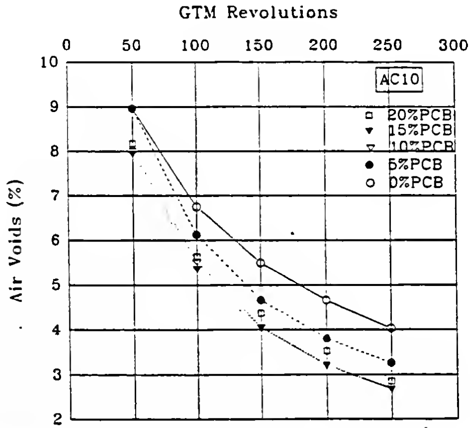


Figure 6.42 Relationship between Air Voids and GTM Revolutions (AC10+PCB)

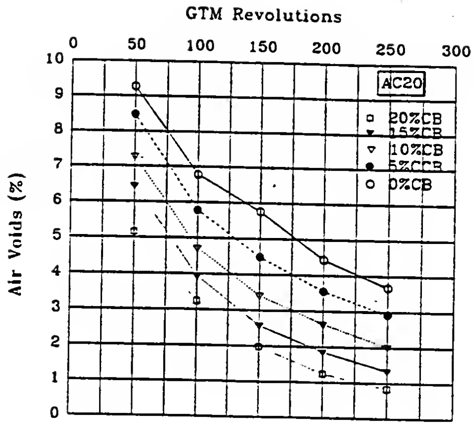


Figure 6.43 Relationship between Air Voids and GTM Revolutions (AC20+CB)

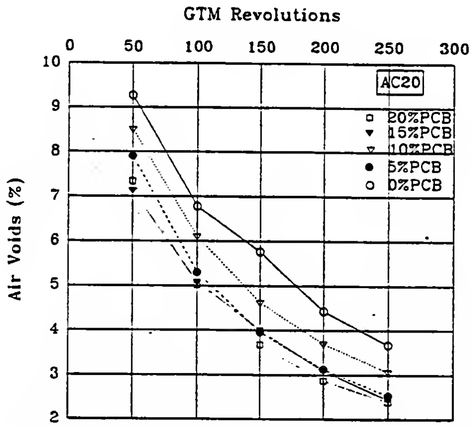


Figure 6.44 Relationship between Air Voids and GTM Revolutions (AC20+PCB)

when the carbon black content is greater than 5 percent, the final air voids are much less than 3 percent.

From Figure 6.44, it can be deduced that the inclusion of PCB in an AC-20 mixture is not as significant as the inclusion of commercial carbon black in an AC-20 mixture, the final percentage of air voids ranging from 2.5 % to 3 %. This variation range is smaller than the one for CB mixtures, which ranges from 3 % to 0.9 %.

The variation of air voids of PCB mixtures is less severe than that of CB mixtures for both grades of asphalt. A large variation of air voids can cause pavement failures associated with the permanent deformation. The potential effects of the inclusion of PCB in both grades of asphalt are summarized as follows:

1) Both grades of asphalt mixtures may be permeable to air and water due to high air voids in the initial stage of construction (Brown et al., 1989; Santucci et al., 1985). The premature cracking and/or raveling potential may be more significant than with PCB mixtures.

2) The rutting potential for both grades of asphalt CB mixtures is higher than that of conventional mixtures and PCB mixtures, because when the air voids of the in-place mixture are less than 3 percent, the permanent deformation is likely to occur due to plastic flow (Brown and Cross,1989).

3) The use of the appropriate amount of PCB can control the variation of air voids. Both 5 and 10 percent PCB mixtures for both grades of asphalt are ideal for this purpose. The appropriate control of air voids could cause higher resistance to rutting and to premature cracking.

6.3.3 Gyratory Compactibility Index

The Gyratory Compactibility Index (GCI)defines the compactibility of the mixture. The Gyratory Compactibility Index can be obtained from the unit weight of asphalt concrete at 30 Revolutions divided by the unit weight of asphalt concrete at 60 Revolutions. The closer the index is to unity, the easier the mixture is to compact. The Gyratory Compactibility Index is obtained in accordance with ASTM D 3387. The Gyratory Compactibility Index for each mixture is summarized in Table 6.6. As can be seen in Table 6.6, there is no difference or difficulty in compaction due to the inclusion of PCB. Both PCB mixtures produce a ratio close to unity. Therefore, the compactibilty of PCB mixtures could be equal to or higher than the CB mixture and the conventional asphalt mixtures.

Table 6.6 Summary of GCI for each mixture.

Asphalt	Additives	0 %	5 %	10 %	15 %	20 %
AC-20	CB	0.94	0.96	0.96	0.96	0.95
	PCB	0.94	0.96	0.96	0.96	0.96
AC-10	CB	0.96	0.95	0.95	0.95	0.96
	PCB	0.96	0.96	0.96	0.96	0.96

6.3.4 Gyratory Stability Index

The stability of a mixture can be estimated by GSI which is related to plastic deformation of pavement. As the GSI value is closer to unity, the mixture becomes more stable and plastic deformation is less likely to occur. Gyratory Stability Index can be

obtained from the relationship between the ratio of the maximum gyratory angle (θ_{max}) and the minimum gyratory angle (θ_{min}), expressed in the equation below;

$$\mathrm{GSI} = \frac{\theta_{\max}}{\theta_{\min}} \tag{6.4}$$

The official criterion for GSI value has not yet been determined. McRae (1993) recommends that a GSI close to unity typically implies a stable mix.. Robert et al. (1991) specifies that “a value significantly above 1.1 usually indicates unstable mixtures.” Research conducted by the Maine DOT suggests that “GSI should be less than 1.15 after 300 revolutions to prevent rutting” , and Illinois DOT studies suggest that “GSI should be less than 1.25 after 300 revolutions” (Zhang et al., 1994). Based on the previous research on GSI values, a GSI value of 1.15 is selected as a criterion in this study.

The relationship between GSI and the number of revolutions for AC-10 and AC-20 mixtures is provided in Figure 6.45 and Figure 6.46, respectively. As can be seen from Figure 6.45 and Figure 6.46, in general, GSI increases with increasing number of revolutions. The rate of variation of GSI is almost constant with increasing GTM revolutions in the PCB mixtures. The rate of change of GSI is more significnt in CB mixtures than PCB mixture.

For AC-10 mixtures, the conventional mixture shows the most stable condition. The PCB mixture is more stable and undergoes less plastic deformation than the CB mixture. The increase in GSI is more significant in high PCB and CB content mixtures.

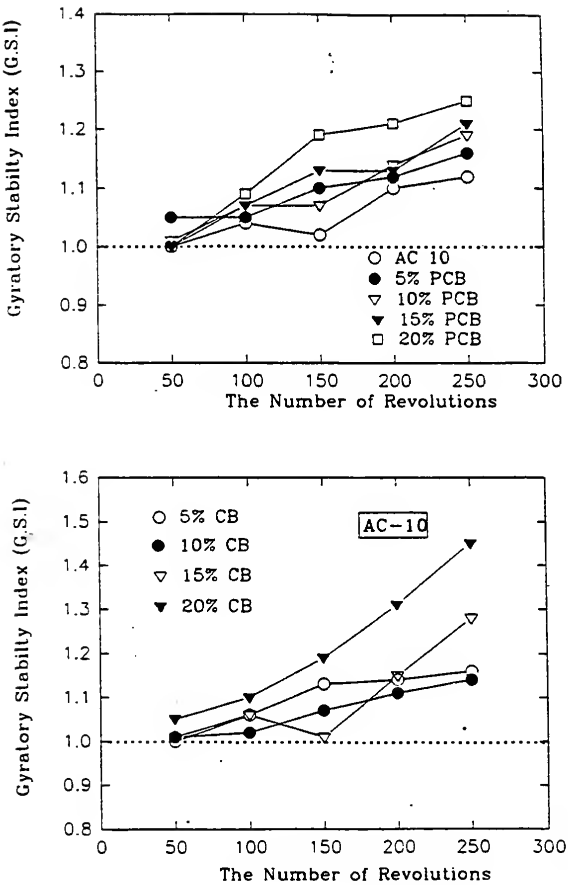
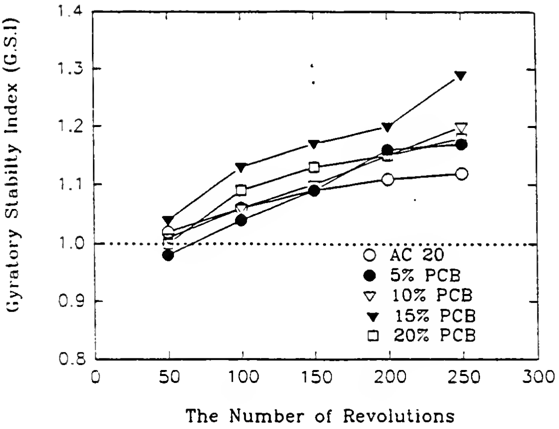


Figure 6.45 Comparison of GSI for AC-10 Mixtures



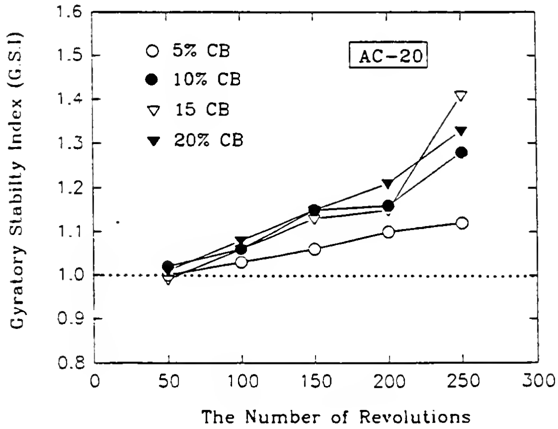
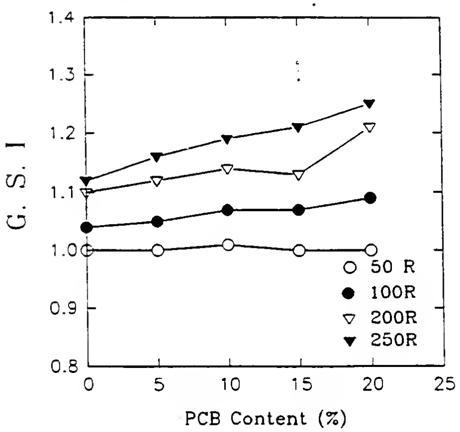


Figure 6.46 Comparison of GSI for AC-20 Mixtures

Conventional AC-20 mixtures prove to be the most stable, while low content PCB and CB mixtures are more stable than high content PCB and CB mixtures. This implies that the inclusion of a high content of PCB and CB increases the deformation potential of the mixture. Comparing the performance of PCB mixtures to those of CB mixtures in terms of GSI, the PCB mixtures perform far better than the CB mixtures. This test result can be compared to the Marshall stability test results. The Marshall stability increases with increasing PCB content, however, it is found from the GTM that the plastic deformation potential is somewhat significant with increasing PCB contents and with increasing the GTM revolutions. This is because the Marshall stability allows no shearing action as the compaction proceeds.

Figure 6.47 and Figure 6.48 show the variation of GSI as a function of PCB and CB content for both grades of asphalt mixtures. It can be observed that GSI is affected by the characteristics of asphalt. Gyratory Stability Index increases with increasing PCB and CB content in AC-10 mixtures; however, GSI increases and then decreases with PCB and CB contents greater than 15% in AC-20 mixtures.

For AC-10 mixtures, there appears to be a different response than for AC-20 mixtures. The variation of GSI in an AC10 PCB mixture is less significant than in an AC-20 mixture, as can be seen in Figure 6.48. The influence of PCB is not so significant as that of CB in both grades of asphalt. Both grades of CB mixture indicated excess plastic deformation above 200 GTM revolutions. Therefore, it can be concluded from the GSI that conventional AC-10 and AC-20 mixtures perform the best, and both grades of PCB modified mixtures perform better than both grades of CB modified mixtures.



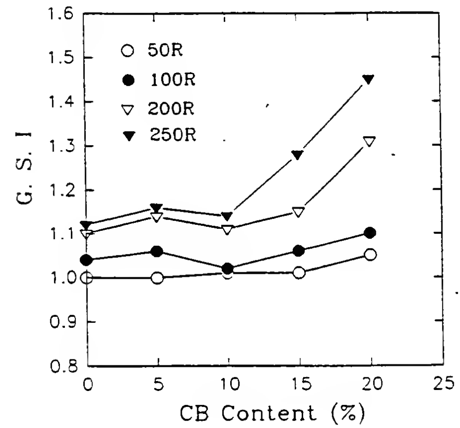
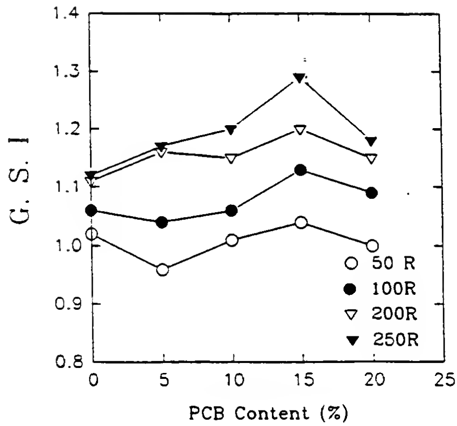


Figure 6.47 Variation of GSI by PCB and CB Contents for GTM Revolutions (AC-10)



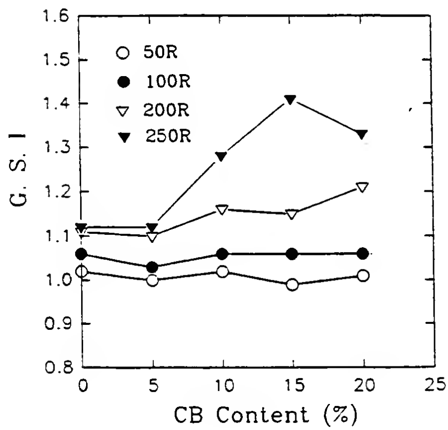


Figure 6.48 Variation of GSI by PCB and CB Contents for GTM Revolutions (AC-20)

Figure 6.49 illustrates the effects of PCB in AC-10 and AC-20 mixtures at 250 GTM revolutions in terms of GSI and percentage of PCB and CB. Conventional AC-10 and AC-20 mixtures appear to be more stable than PCB and CB mixtures. For softer asphalt mixtures, the GSI value increases with increasing PCB and CB contents. This implies that more plastic deformation is expected in higher PCB content mixtures. The CB mixture exhibited more extreme variation than the PCB mixture, as CB content increases. Particularly, the variation of 20% GSI in the CB mixture is very remarkable.

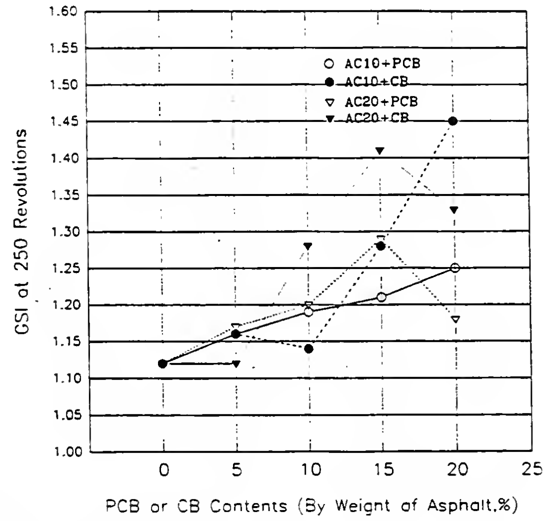


Figure 6.49 GSI at 250 Revolutions

6.3.5 Gyratory Shear

Gyratory Shear (Sg) indicates the shear resistance of a mixture. A reduction of this value during the compaction process indicates loss of stability. Currently, an official criterion for Sg is not available. Research from the Maine DOT (1992) recommends 35 psi (241.32 kPa) after 300 revolutions as the minimum Sg value (Zhang et al., 1994). Since in this study the maximum is 250 revolutions, 40 psi has been selected for the Sg criterion. Different models of GTM have different relationships for determination of Sg. Gyratory Shear (Sg) for GTM model 8A/6B/4C can be obtained by the following relationship:

$$Sg = 8.27 \times \frac{p}{h} \tag{6.5}$$

where, p = vertical pressure (psi)

h = height of specimen (inches)

Figure 6.50 presents the effect of PCB and CB in AC-10 mixtures. The conventional AC-10 mixture remains very consistent after 100 revolutions, despite an increase in GTM revolutions. The PCB mixtures exhibits higher Sg values; however, the variation of Sg in the PCB mixtures is more significant than that of Sg in the conventional AC-10 mixtures. Conversely, the variation of Sg in the PCB mixtures is less significant than that of Sg in the CB mixtures. The latter is more marked when GTM revolutions increase. Figure 6.51 shows the effect of PCB and CB in AC-20 mixtures. Both PCB and CB appear to maintain the same general trend in AC-20 mixtures. This result may be explained by the variation of air voids; since the percentage of air voids of conventional

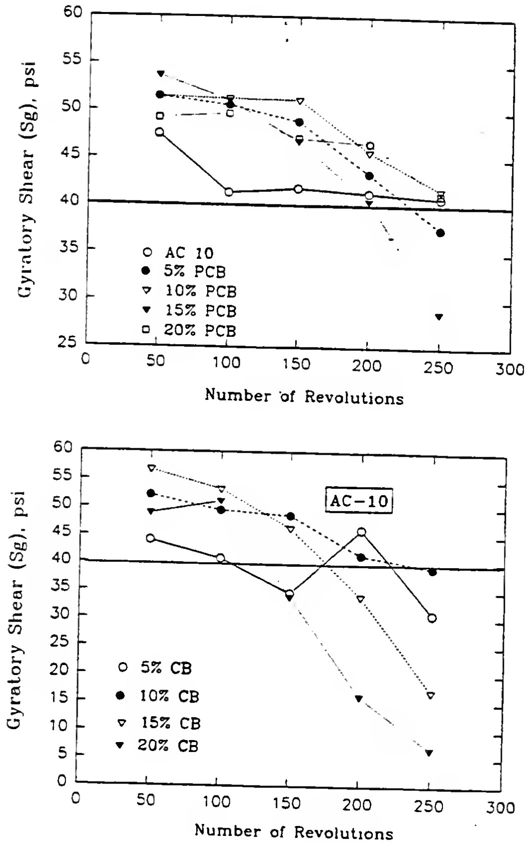


Figure 6.50 Comparison of Sg by GTM Revolutions (AC-10)

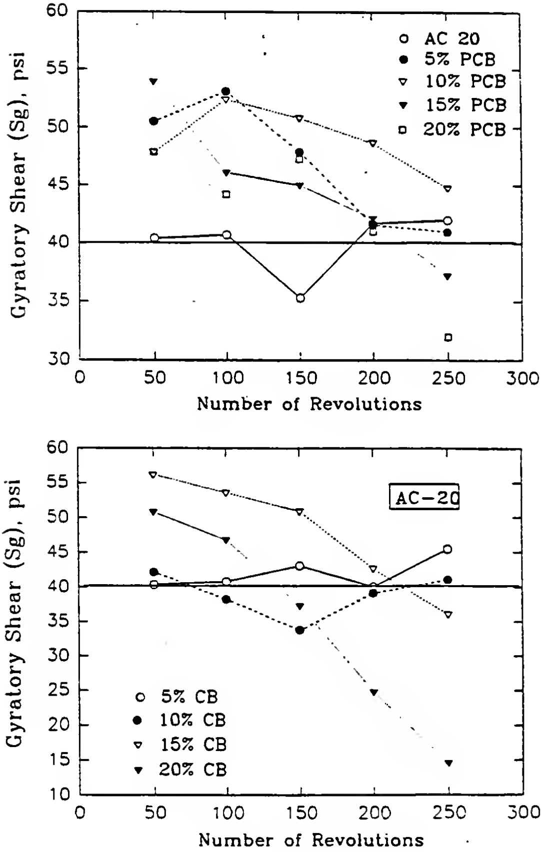


Figure 6.51 Comparison of Sg by GTM Revolutions (AC-20)

mixtures is lower than that of PCB and CB mixtures. The densification effect by the traffic in conventional mixtures is less significant than in PCB and CB mixtures. Five percent and ten percent PCB mixtures show the best performance in terms of gyratory shear, as shown in Figures 6.50 and 6.51. This implies that the shear resistance of the mixture can be reinforced by the inclusion of 5% to 10% PCB in both asphalt mixtures.

6.3.6 Gyratory Shear Factor

The GSF is a factor of safety type index; when the GSF value is less than unity, there is inadequate shear strength for the anticipated maximum shear in the pavement. The Gyratory Shear Factor (GSF) can be obtained from the relationship between the gyratory shear estimated and the theoretical maximum induced shear stress. The theoretical maximum induced shear stress (τ_{max}) for a strip load on a homogeneous elastically isotropic mass is

$$\tau_{max} = \text{Vertical Pressure} / \pi = 120 / 3.14 = 38.2 \text{ psi } (263.4 \text{ kPa}) \qquad (6.6)$$

and the GSF is,

$$GSF = Sg / \tau_{max} \qquad (6.7)$$

Therefore, τ_{max} = 38.2 psi is fixed so that GSF provides exactly the same trend as gyratory shear. McRae (1993) states in the GTM manual that the GSF value is not valid if the GSI is greater than unity. Because pavement design should allow a certain amount of deformation, GSI and GSF should be considered at the same time. As mentioned earlier, GSI is a function of plastic deformation of the mixture, and GSF is related to the shear

strength of the mixture. Therefore, it is desirable for the mixture to meet these two criteria so that less plastic deformation and higher shear resistance can be obtained.

Table 6.7 and Table 6.8 summarize GSI and GSF at GTM 100 revolutions and at GTM 250 revolutions, respectively. For 100 revolutions in Table 6.5, all mixtures passed the design criteria. In particular, the shear resistances of most of the PCB mixtures in both grades of asphalt have showed the superior performance of all other mixtures.

However, if the revolutions increase, GSI and GSF are significantly affected by the increase, just as increase in traffic volume increases the plastic deformation and decreases the stabilty of pavement. As can be seen in Table 6.6, only 7 mixtures out of 18 mixtures pass the design criteria. That is, about 39 percent of the mixtures meet the design criteria. All conventional mixtures in both grades of asphalt resulted in good performance. Furthermore, while 5 % and 10 % PCB mixtures for both grades of asphalt, which met the design criteria, showed desirable performance and higher shear resistance than any other mixture, however, for CB mixtures, only one CB mixture (AC-20+5 % CB), passed the design criteria.

From this analysis, two things can be concluded: a) the inclusion of PCB in asphalt mixture strengthens the shear resistance of the pavement; b) plastic deformation can be controlled by the appropriate amount of PCB.

Table 6.7 Analysis of GSI and GSF at GTM 100 Revolutions

	AC20+PCB		AC20+CB		AC10+PCB		AC10+CB	
Content	GSI	GSF	GSI	GSF	GSI	GSF	GSI	GSF
0 %	1.06	1.07	1.06	1.07	1.04	1.08	1.04	1.08
5 %	1.04	1.39	1.03	1.07	1.05	1.32	1.06	1.07
10 %	1.06	1.37	1.06	1.0	1.07	1.34	1.02	1.30
15 %	1.13	1.21	1.06	1.4	1.07	1.34	1.06	1.40
20 %	1.09	1.16	1.08	1.23	1.09	1.30	1.10	1.34

Table 6.8 Analysis for GSI and GSF at GTM 250 Revolutions

	AC20+PCB		AC20+CB		AC10+PCB		AC10+CB	
Content	GSI	GSF	GSI	GSF	GSI	GSF	GSI	GSF
0 %	1.12	1.10	1.12	1.10	1.12	1.07	1.12	1.07
5 %	1.17	1.07	1.12	1.19	1.16	0.98	1.16	0.81
10 %	1.20	1.17	1.28	1.08	1.19	1.09	1.14	0.70
15 %	1.29	0.97	1.41	0.94	1.21	1.09	1.28	0.45
20 %	1.18	0.84	1.33	0.38	1.25	1.08	1.45	0.18

Note : Shaded cells mean that mixtures are out of the design criteria (GSI ≤ 1.2 and GSF ≥ 1.0)

6.3.7 Gyratory Shear Modulus

The Gyratory Shear Modulus is expressed through the following relationship;

$$Gg = \frac{Sg}{\tan \theta_o} \tag{6.8}$$

where, θ_o = Initial Gyratory Shear Angle

The initial Gyratory Shear Angle (θ_o) is identical for a machine; therefore, the Gyratory Shear Modulus shows the same trend as Gyratory Shear.

6.3.8 Gyratory Compression Modulus

The Gyratory Compression Modulus (Eg) can be obtained from the following equation:

$$Eg = 2Gg\,(1+\mu) \tag{6.9}$$

where, Gg = Gyratory shear modulus

μ = Poisson's ratio

As can be seen from the equation above, the Eg is a function of the Gyratory Shear Modulus when Poisson's ratio is given. Therefore, Eg also shows the same trend as the Gyratory Shear (Sg).

The comparison of Gyratory Shear Factor, Gyratory Shear and Gyratory Compression Modulus discussed above are presented in Appendix G. It should be noted that while the CB mixtures showed better performance in low revolutions (both 50 and

100 revolutions), the PCB mixtures showed better performance at 150 revolutions or more. This indicates that PCB mixture can be more stable and durable than conventional asphalt mixture and CB mixture in terms of long periods of traffic loading.

6.3.9 Unit Weight

Figure 6.52 and Figure 6.53 show the variation of the unit weight of both mixtures with GTM revolutions. The initial rate of increase in unit weight, for 50 to 150 revolutions, is very significant. The unit weight of CB mixtures steadily increases as the CB content increases from 50 to 250 revolutions.

However, the PCB mixture shows different behavior in terms of unit weight; the variation of unit weight is not as significant as for CB mixtures. The unit weight in terms of PCB content is almost the same from 5 percent to 15 percent PCB, and slightly decreases beyond 15 percent PCB.

The different behavior of PCB mixtures in unit weight could be attributed to the different specific gravity of the two materials. The specific gravity of CB is approximately 1.95 and that of PCB is 1.49. Another reason for this might be the difference of the particle sizes of both material. The PCB involves much coarser particles than carbon black does, therefore, when the asphalt is replaced by the PCB, more volume is occupied by the PCB. Thus the unit weight of the PCB mixture is lower than that of the CB mixture.

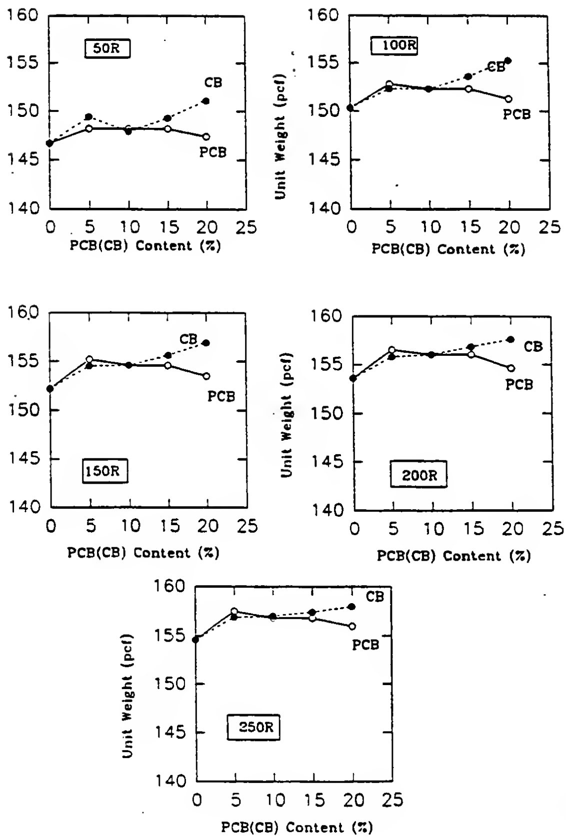


Figure 6.52 Variation of the Unit Weight (AC-10)

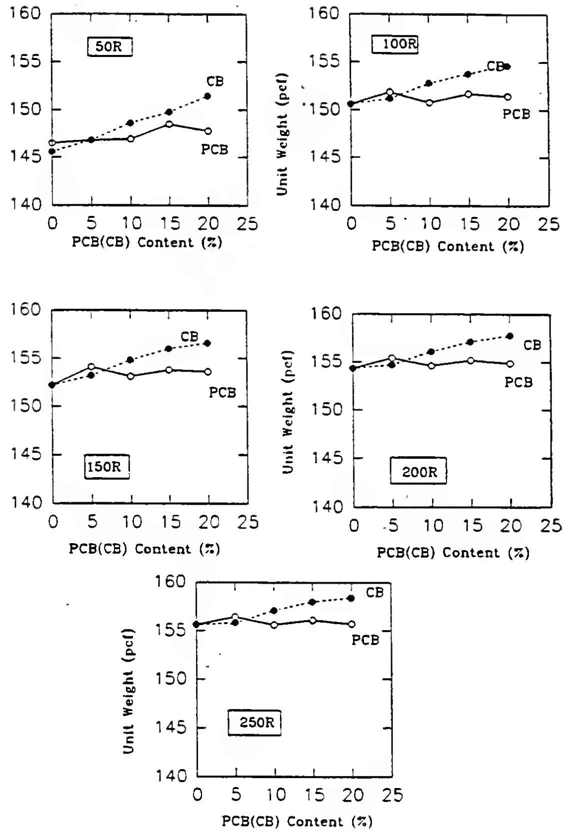


Figure 6.53 Variation of the Unit Weight (AC-20)

6.4 Dynamic Confined Creep Test

6.4.1 Test Results

The total permanent deformations at the end of each rest period were obtained through the creep test. These results were plotted in terms of strain (in./in.) vs. repeated loading time (sec). Figure 6.54 and Figure 6.55 present the plots for the testing results of AC10 with 5 percent PCB and AC20 with 5 percent PCB mixture, respectively. The amount of permanent deformation depends on the grade of asphalt and types of mixtures. However, the general pattern of the curve for each mixture is almost identical. The rest of the plots are presented in Appendix H.

6.4.2 Test Data Analyses

The influence of the inclusion of CB and PCB in both asphalt types was examined through preliminary analysis of the creep data. The analyses conducted were the mix stiffness modulus, the creep compliance, the corrected total creep and the corrected cumulative creep. After these analyses were completed, regression was carried out by using corrected cumulative creep data so that the creep potential for each mixture could be examined.

6.4.3 Mix Stiffness

The stiffness modulus was originally defined by Van der Poel (1954)

$$S(t) = \frac{Tensile\ Stress}{Tensile\ Strain} \tag{6.10}$$

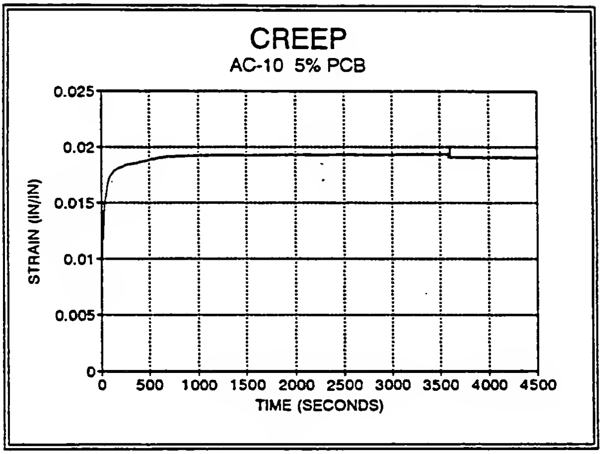


Figure 6.54 Creep Test Results (AC10 + 5% PCB)

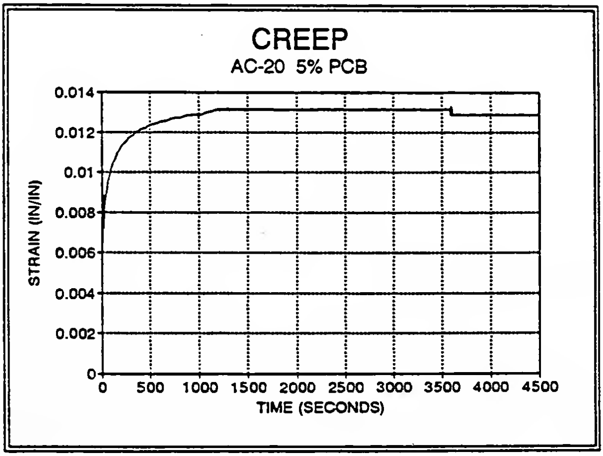


Figure 6.55 Creep Test Results (AC20 + 5% PCB)

Based on test data, strain and applied stress were used to estimate the mix stiffness (Smix) as a function of loading time using the following equation (Hills et al., 1974):

$$S_{mix}(T,t) = \frac{\sigma}{\varepsilon_t} \tag{6.11}$$

where, $S_{mix}\ (T,t)$ = Mix stiffness at a specified temperature (T) and time of loading (t)

σ = applied stress (120 psi), and

ε_t = axial strain at $t = \Delta h/h$, where Δh is change in height of specimen, and h is height of specimen.

AC-10 + CB Mixtures

Figure 6.56 shows the mix stiffness of AC-10 with CB mixtures. As shown in Figure 6.56, the 10 percent CB mixture showed the most significant decrease of rutting potential in the initial stage. The stiffness trends for 20 percent and 15 percent of CB mixtures are almost identical; the mix stiffness trends for the final stage of the two mixtures are the same. Inclusion of CB for AC-10 mixtures resulted in increasing the mix stiffness. As CB contents increase, the mix stiffness increases.

AC-10 +PCB Mixtures

Figure 6.57 shows the mix stiffness for AC-10 with PCB mixtures. The PCB mixtures appear to have the same trend as CB mixtures. The only difference is that the 15 % PCB mixture showed the most significant increase of stiffness in this mixture type. As can be seen, all mixtures showed an increase in stiffness with increasing PCB contents.

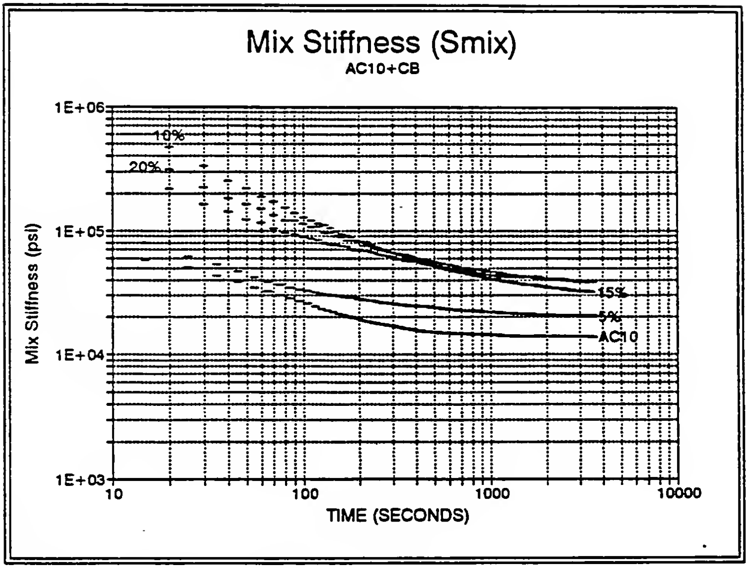


Figure 6.56 Comparison of Mix Stiffness for AC10+CB Mixture

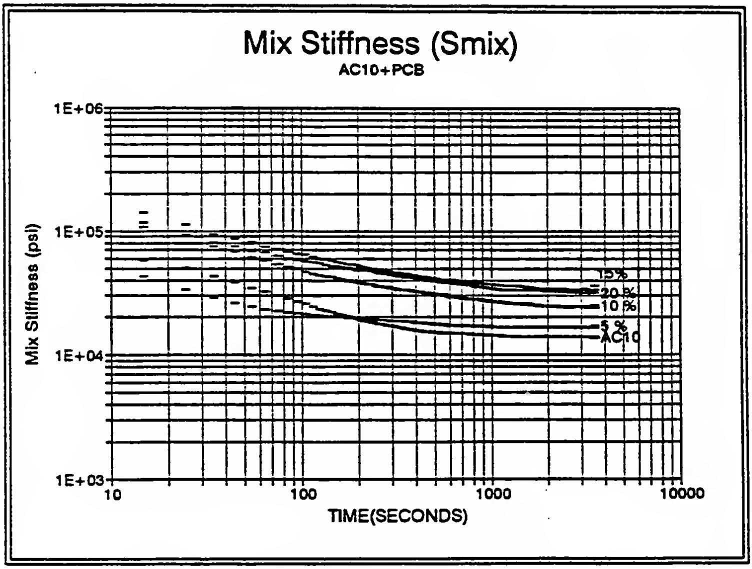


Figure 6.57 Comparison of Mix Stiffness for AC10+PCB Mixture

AC-20 + CB Mixtures

Figure 6.58 presents the mix stiffness for AC-20 with CB mixtures. The mix stiffness decreases with increasing CB content, which is opposite to the trend shown by AC-10 CB mixtures. The stiffness effect is not as significant for AC-20 mixtures as it is for AC-10 mixtures. Rather, the inclusion of CB in AC-20 decreases the rutting potential.

AC-20 + PCB Mixtures

In Figure 6.59, the variation of the mix stiffness for AC-20 with PCB mixtures is illustrated. In this case, the stiffness decreases with the inclusion of PCB. As shown in Figure 6.59, 5 % of the mixture resulted in the most significant decrease of stiffness. As observed in AC-20 CB mixtures, the inclusion of PCB in AC-20 causes the rutting potential to increase.

After the completion of the analysis of the mix stiffness, a particular trend was found: stiffness of AC-10 mixtures for both CB and PCB increases when the CB and the PCB contents are increased. However, when the CB and PCB contents are increased in AC-20 mixtures, the stiffness of the mixture decreases. Therefore, use of CB or PCB in AC-20 is not recommended.

The increase of stiffness is more significant in PCB mixtures for both asphalt types. This general trend agrees with the Gyratory testing machine results. However, the PCB contents used are not correlated with each other. In the Gyratory testing machine, 10 % of the PCB mixture proved to be the most significant. On the other hand, in creep test results, the rutting potential decreased with increasing PCB contents. This difference could

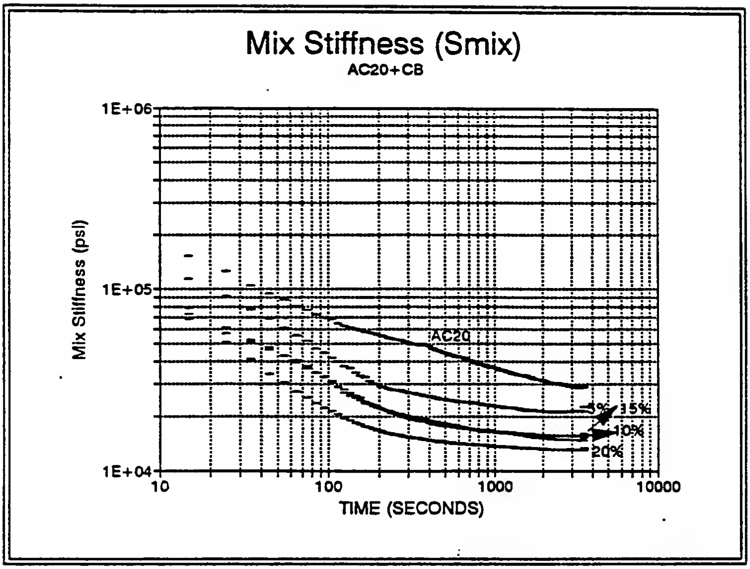


Figure 6.58 Comparison of Mix Stiffness for AC20+CB Mixture

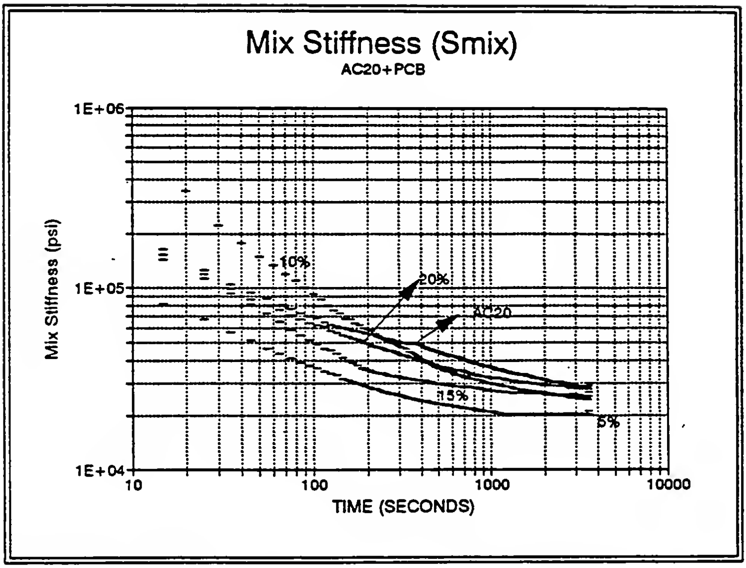


Figure 6.59 Comparison of Mix Stiffness for AC20+PCB Mixture

be caused by the particle orientations in the mixtures due to the different compaction processes.

6.4.4 Creep Compliance

Creep compliance can be calculated from the creep test data. The creep compliance can be used to study the viscoelastic characteristics of the mixes. The creep compliance is the inverse of mix stiffness. Therefore, an increase of creep compliance represents an increase of the rutting potential in the pavement system. The creep compliance is obtained by dividing the strain by the applied stress (Hills, 1973), as shown in the equation below:

$$J(t) = \frac{\varepsilon_{(t)}}{\sigma} = \frac{1}{S_{mix}} \tag{6.12}$$

where, ε_t = axial strain

σ = applied stress

S_{mix} = mix stiffness

Figure 6.60 and Figure 6.61 show the creep compliance for AC-10 with PCB mixtures and AC-20 with PCB mixtures, respectively. The creep compliance for AC-10 with PCB decreases with increasing PCB contents. The inclusion of PCB in this case causes the rutting potential to decrease. However, the creep compliance for AC-20 with PCB mixtures increases with increasing PCB contents. Recall that the creep compliance is the inverse of the mix stiffness.

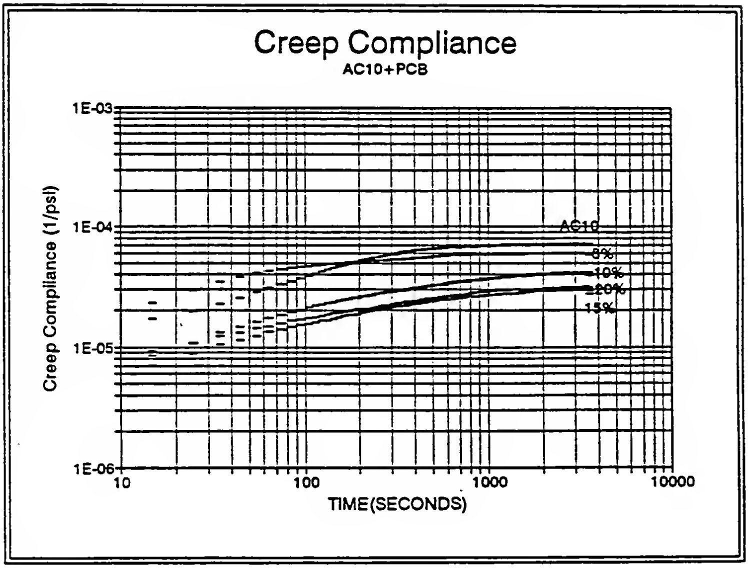


Figure 6.60 Comparison of Creep Compliance for AC10+PCB Mixture

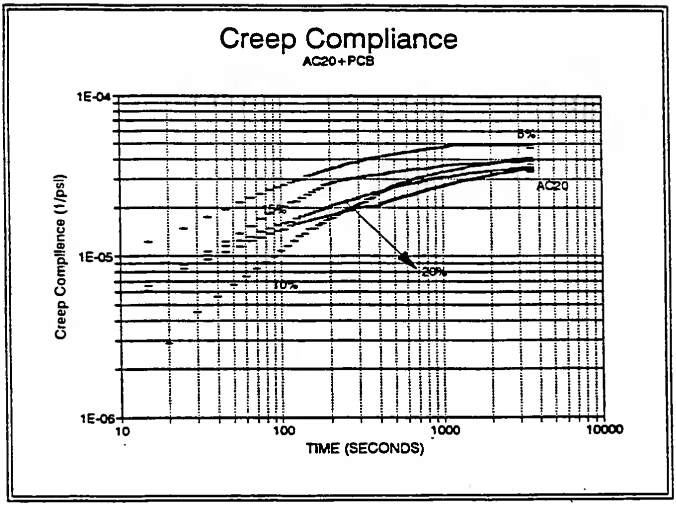


Figure 6.61 Comparison of Creep Compliance for AC20+PCB Mixture

6.4.5 Corrected Creep

Corrected creep data were interpreted to observe the total strain variation of the mixtures. The corrected creep data were obtained by offsetting the loading cell seating time. The offset time is the time at which the loading cell makes contact with the specimen surface, which was generally between 47 and 57 seconds.

<u>AC-10 + CB Mixtures</u>

Corrected creep results for AC-10 as a function of loading time (sec) are shown in Figure 6.62. The decrease of deformation is significant with increasing CB contents up to 10 percent. However, when the increase of CB content was higher than 10 %, the decrease is not as significant.

<u>AC-10 + PCB Mixtures</u>

Figure 6.63 shows the effect of the inclusion of PCB in AC-10 mixtures. Deformation decreases with increasing PCB content. The decrease in deformation rate is slightly less than in CB mixtures, and the relationship between the PCB content and the decrease in deformation is more evident than in the CB mixtures.

<u>AC20 + CB Mixture</u>

Figure 6.64 illustrates the relationship between corrected creep and different contents of CB. The total deformation increases with increasing CB content. This trend is totally opposite to the AC10 with CB. Ten percent and fifteen percent have an overlap during the first 1500 seconds; after the first 1500 seconds the total

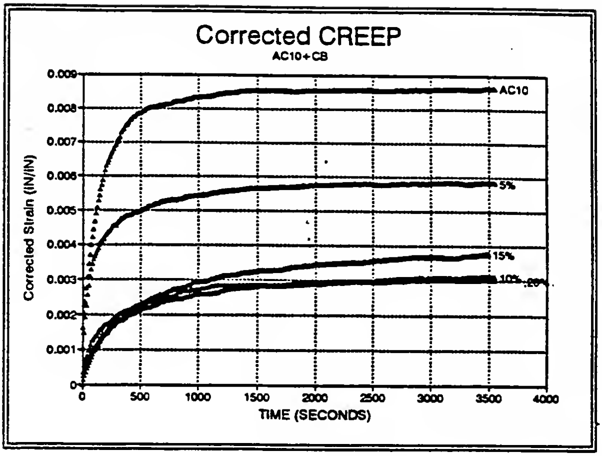


Figure 6.62 Comparison of Corrected Creep for AC10+CB Mixture

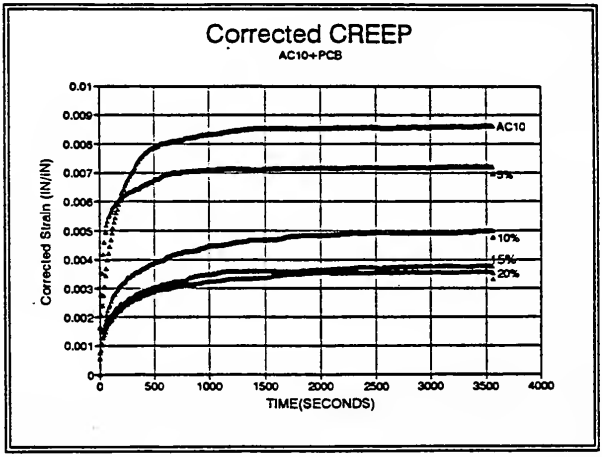


Figure 6.63 Comparison of Corrected Creep for AC10+PCB Mixture

deformation of the 10 percent CB mixture increases more than that of the 15 percent CB mixture.

AC20 + PCB Mixture

Figure 6.65 shows the corrected creep results for AC-20 with PCB. The relationship shows somewhat different results from the AC-10 PCB mixtures. The inclusion of PCB in the AC-20 mixture caused the total deformation to increase. The 5 percent PCB mixture resulted in the most significant increase of deformation. With increasing PCB content, the deformation eventually drops. While 5 % to 15 % PCB mixtures showed an increase in deformation, the 20 % PCB mixture showed a slight decrease of the total deformation.

6.4.6 Corrected Cumulative Creep

As shown in Figure 6.66, the corrected cumulative creep for CB mixtures decreases with increasing CB contents. The creep potential slope generally decreases as the CB content increases. Figure 6.67 shows the corrected cumulative creep for AC-10 PCB mixtures. The cumulative creep is similar to the CB mixtures. In this case, the 15 percent mixture resulted in the smallest cumulative creep. The general trend cannot be explained in terms of PCB contents and creep behavior because of the variability of the test results.

Figure 6.68 shows the cumulative creep results for AC-20 CB mixtures. As CB content is increased, the cumulative creep increases and the slope becomes steeper. This trend agrees with the results for the mix stiffness and the corrected creep. The AC-20 PCB mixtures showed somewhat different results as compared to AC-20 CB mixtures.

This difference is shown in Figure 6.69. An increase of PCB content did not contributed to the decrease of cumulative creep. The inclusion of PCB in AC-20 mixtures caused the cumulative creep to increase.

The corrected cumulative creep was interpreted to identify the slope of the creep test results. The slope of the corrected cumulative creep provides the creep potential for each mixture. When the slope is steeper, the rutting potential is higher. Figure 6.70 shows the variation of the creep potential for each mixture. As can be seen in Figure 6.70, the inclusion of PCB and CB in AC-10 mixtures is more effective than in AC-20 mixtures. This trend was found in the previous commercial carbon black studies; the effects of the carbon black filler on the properties of the asphalt used varied somewhat depending on the characteristics of the asphalt (Vallerga and Gridley, 1980, Khosla, 1991).

Based on the regression results, the creep potential can be predicted by the value of the slope for each mixture. The slope of the AC-10 PCB mixtures are less than the AC-10 CB mixtures, and thus less creep is anticipated for the AC-10 PCB mixtures. Table 6.9 presents results of the linear regression for cumulative creep data. The coefficient of determination is higher than 0.96 for all cases.

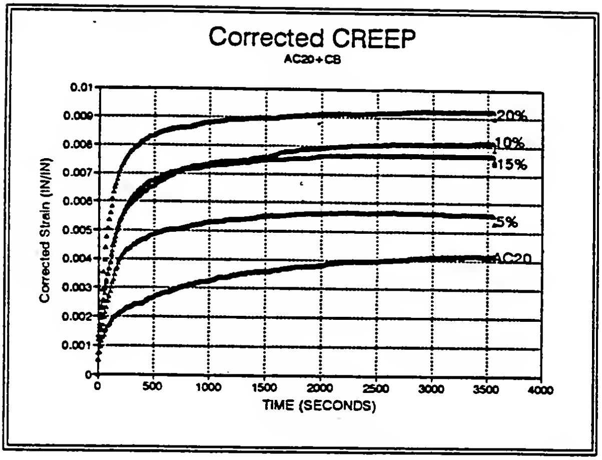


Figure 6.64 Comparison of Corrected Creep for AC20+CB Mixture

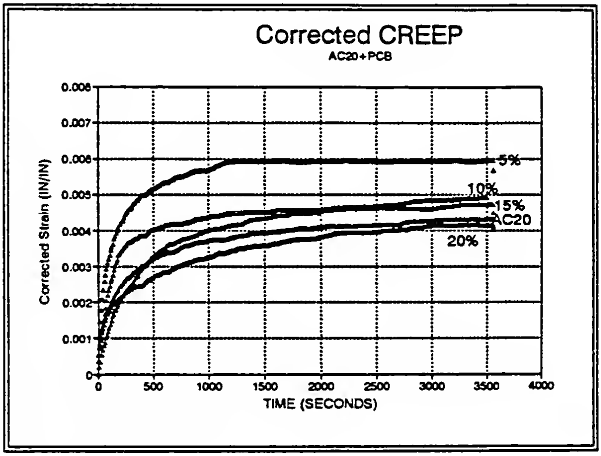


Figure 6.65 Comparison of Corrected Creep for AC20+PCB Mixture

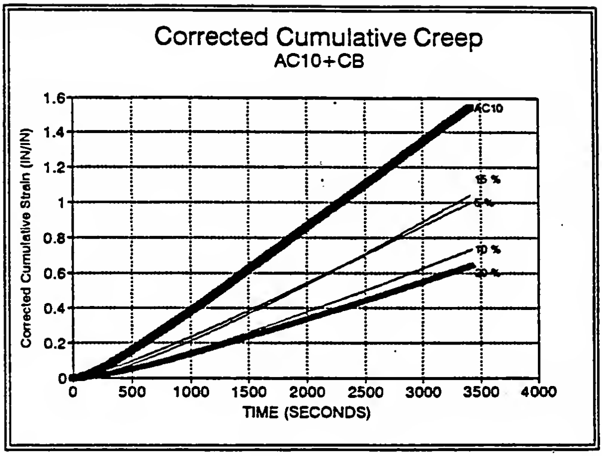


Figure 6.66 Comparison of Corrected Cumulative Creep for AC10+CB Mixture

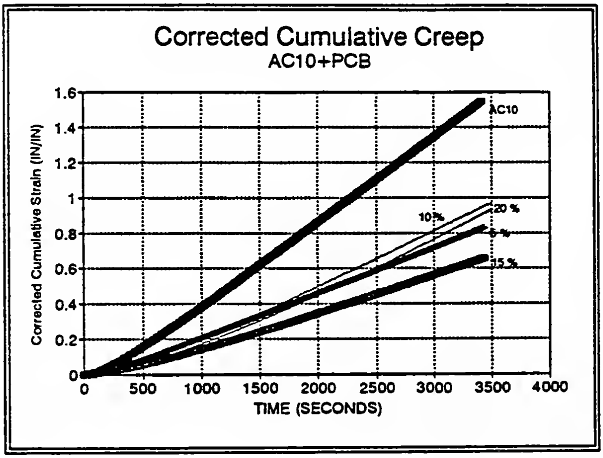


Figure 6.67 Comparison of Corrected Cumulative Creep for AC10+PCB Mixture

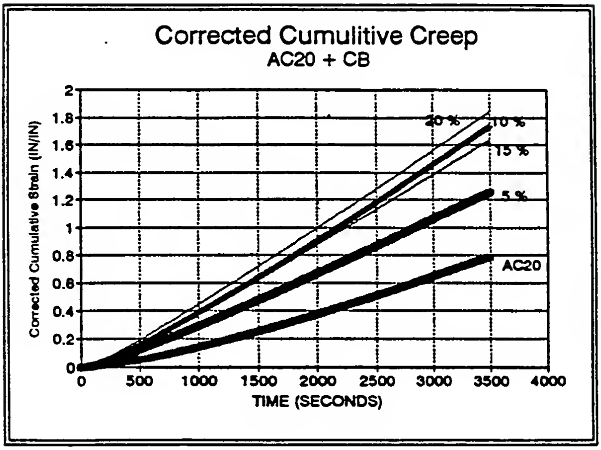


Figure 6.68 Comparison of Corrected Cumulative Creep for AC20+CB Mixture

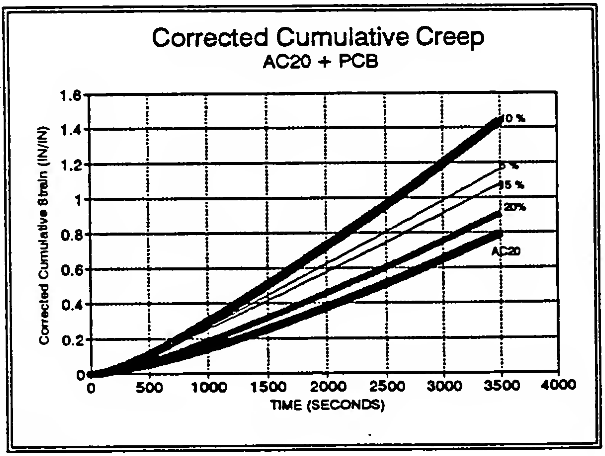


Figure 6.69 Comparison of Corrected Cumulative Creep for AC20+PCB Mixture

Table 6.9 The Results of Linear Regression for Cumulative Creep

Asphalt Mixture	CB (PCB) Content	r^2	X-Coefficient
AC10 + CB	0 %	0.99	0.000438
	5 %	0.99	0.000278
	10 %	0.98	0.000198
	15 %	0.97	0.00028
	20 %	0.98	0.000177
AC10 + PCB	5 %	0.99	0.000234
	10 %	0.98	0.00026
	15 %	0.98	0.000179
	20 %	0.97	0.000241
AC20 + CB	0 %	0.96	0.000204
	5 %	0.99	0.000344
	10 %	0.99	0.000469
	15 %	0.99	0.000448
	20 %	0.99	0.000508
AC20 + PCB	5 %	0.99	0.000319
	10 %	0.98	0.000381
	15 %	0.99	0.000296
	20 %	0.98	0.000242

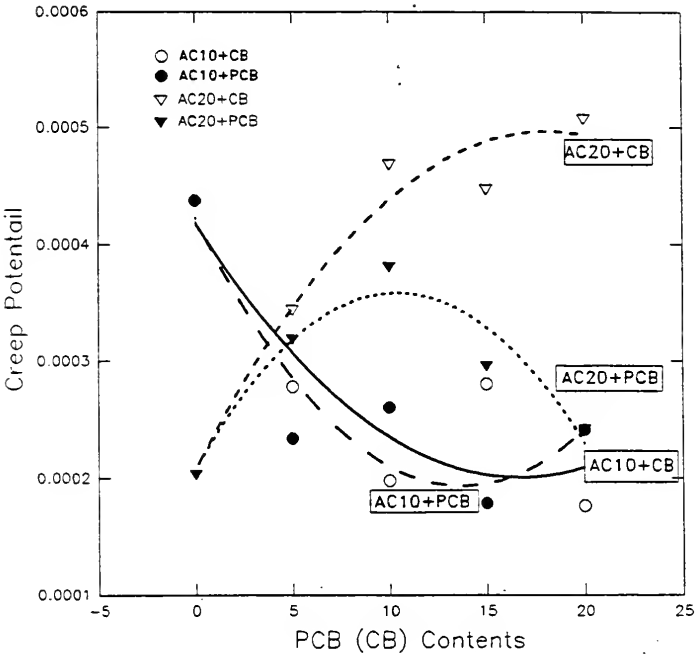


Figure 6.70 Variation of Creep Potential for Each Mixture

6.5 Resilient Modulus testing

6.5.1 Test Results

The resilient modulus (MR) represents the ratio of an applied stress to the recoverable strain that takes place after the applied stress has been removed. The results of the resilient modulus testing for the AC-10 mixtures and the AC-20 mixtures are summarized in Table 6.10 and Table 6.11, respectively. The horizontal displacement and applied load were used to calculate the resilient modulus for each specimen. As mentioned in the previous chapter, the tests were performed at two different temperatures.

Table 6.10 The Test Results for AC-10 Mixtures

Mixture	Horizontal Displacement (mm) (Average))		Applied Load (KN) (Average)	
	5°C	25°C	5°C	25°C
AC-10	0.001135	0.00127	0.252	0.246
AC10 + 5% CB	0.001013	0.00145	0.248	0.246
AC10 + 10 % CB	0.001184	0.00109	0.247	0.246
AC10 + 15 % CB	0.001032	0.001168	0.248	0.246
AC10 + 20 % CB	0.001062	0.001211	0.249	0.247
AC10 + 5 % PCB	0.00094	0.001086	0.249	0.248
AC10 + 10 % PCB	0.000928	0.001062	0.249	0.248
AC10 + 15 % PCB	0.001904	0.001044	0.247	0.246
AC10 + 20 % PCB	0.001154	0.001038	0.254	0.247

Table 6.11 The Test Results for AC-20 Mixtures

Mixture	Horizontal Displacement (mm)		Applied Load (KN)	
	5°C	25°C	5°C	25°C
AC-20	0.001167	0.001306	0.250	0.247
AC20 + 5 % CB	0.001050	0.001099	0.230	0.251
AC20 + 10 % CB	0.000971	0.001129	0.249	0.252
AC20 + 15 % CB	0.001062	0.001184	0.248	0.249
AC20 + 20 % CB	0.000977	0.001080	0.255	0.251
AC20 + 5 % PCB	0.001878	0.000977	0.245	0.251
AC20 + 10 % PCB	0.000915	0.001007	0.239	0.256
AC20 + 15 % PCB	0.001062	0.000861	0.241	0.250
AC20 + 20 % PCB	0.000993	0.001038	0.254	0.247

6.5.2 Test Data Analysis

The resilient modulus is calculated using the following equation:

$$M_R = \frac{P(0.27 + \nu)}{H \times t} \tag{6.13}$$

Where,

M_R = Total resilient modulus (MPa)

P = Load applied (N)

ν = Poisson's ratio (assumed to be 0.35)

H = Total recoverable horizontal deformation (mm)

t = Thickness of specimen (mm)

Figure 6.71 shows the variation of the resilient modulus with increasing PCB and CB content. The test results in Figure 6.71 indicate that the resilient modulus of the PCB and the CB mixtures is higher than the conventional mixtures at both low and high temperatures. The resilient modulus at low temperature (5°C) increases with increasing PCB content to 10 % and then decreases slightly. At high temperature (25°C), the resilient modulus increases with increasing PCB and remains constant. The pyrolized carbon black mixtures produce a resilient modulus that increases with increasing PCB content at low temperatures. This trend continues at high temperatures.The same general trend appears to be maintained in the CB mixtures, however, the resilient modulus of the CB mixtures is generally lower than that of the PCB mixtures.

Figure 6.72 shows AC-20 mixture test results. The resilient modulus is increased with the inclusion of PCB and CB at both low and high temperatures. In particular, at high temperatures (25°C), the resilient modulus of the PCB mixtures indicates significant increase and remains almost constant. The CB mixtures shows the same trend. The inclusion of PCB and CB in AC-20 mixtures also shows the increases of the resilient modulus at both low and high temperatures.

The resilient modulus of PCB mixtures is generally higher than for CB mixtures at both low and high temperatures. It is observed from the resilient modulus test that the effect of PCB is more significant at high temperature than at low temperature. Khosla (1991) indicated the same conclusion with the commercial carbon black modified asphalt concrete.

As mentioned earlier, the performance of both CB modified mixtures and PCB modified mixtures is dependent upon the characteristics of the asphalt. The resilient modulus is effected by the asphalt type and the asphalt temperature. The use of PCB in AC-20 mixtures would increase the resilient modulus at both low and high temperatures. The use of PCB in AC-10 at low temperature provides a lesser effect than in AC-20 mixtures on the resilient modulus, however, increase of the resilient modulus at high temperature would be significant. Therefore, it can be concluded that the inclusion of PCB in both grades of asphalt decreases the temperature susceptibility at high service temperatures without affecting the resilient modulus at low service temperatures (Khosla, 1991).

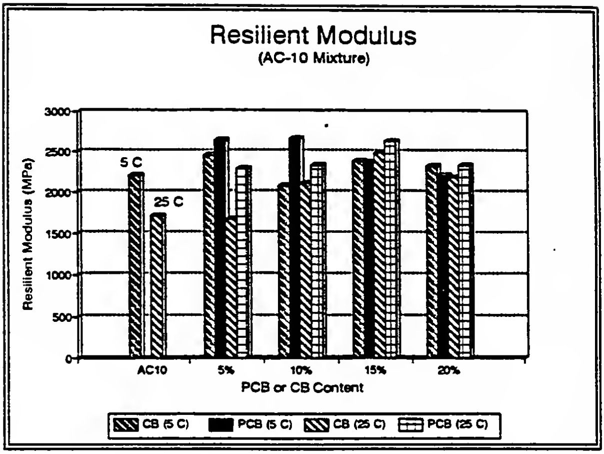


Figure 6.71 The Resilient Modulus of the AC-10 Mixtures.

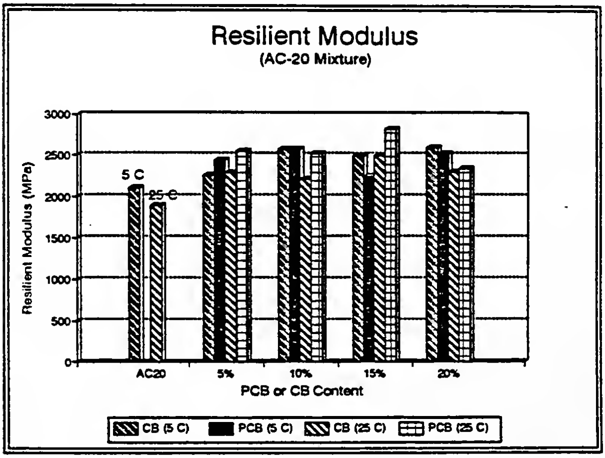


Figure 6.72 The Resilient Modulus of the AC-20 Mixtures

6.6 Hamburg Wheel Tracking Device

6.6.1 Test Results

Ten sets of duplicate sample slabs were tested to evaluate the stripping potential and resistance. As mentioned earlier, 10 % and 15 % CB and PCB mixtures were tested. The selection of the mixtures was made based on results from the Gyratory Testing Machine, because these mixtures showed good performance in terms of Gyratory Stability Index and Gyratory Stability Factor. The test results are given to show the relationship between permanent deformation (mm) vs. numbers of wheel passes. Figure 6.73 and Figure 6.74 show the test results for AC-20 mixtures and AC-20 10% PCB mixtures, respectively. The rest of the test results are provided in Appendix I.

6.6.2 Analysis of Test Data

Figure 6.75 presents the relationship between the impression depth and the number of wheel passes. According to Hines (1991), the Hamburg Wheel Tracking Device provides four kinds of information, which are: post compaction, creep slope, stripping inflection point and stripping slope. Only the stripping inflection point and stripping slope will be considered in the analysis of test data. The stripping inflection point is the number of wheel passes at which the onset of stripping is identified and represents the stripping potential of the pavement. It is reported that the mixture begins to suffer damage by the water at this point (Elf Industries, 1992). Therefore, a higher stripping inflection point would indicate that a pavement would be less likely to strip. Aschenbrener et al (1994) reported the correlation of the stripping inflection point and stripping observed in pavements of known field performance based on the Hamburg Wheel Tracking Device at a

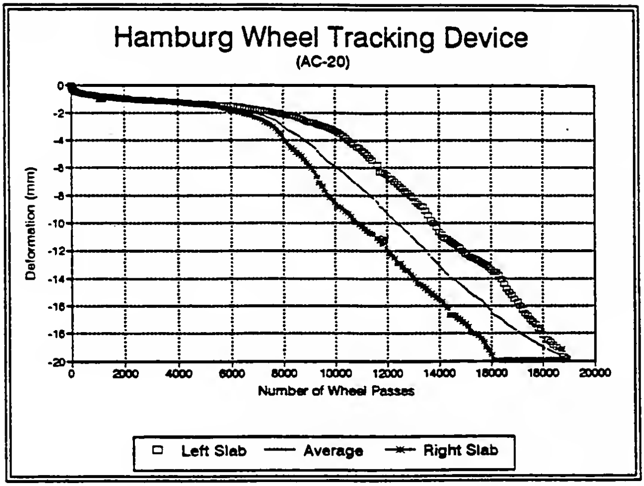


Figure 6.73 Test Results for Hamburg Wheel Tracking Device (AC-20)

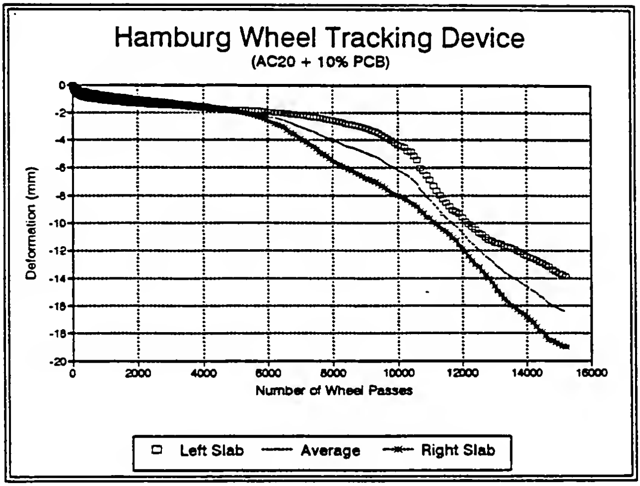


Figure 6.74 Test Results for Hamburg Wheel Tracking Device (AC20 + 10% PCB)

temperature of 122°F (50°C). This showed that a stripping inflection point at around 16,000 passes correlated with a good pavement performance; a stripping inflection point around 8,400 passes indicated excessive maintenance problems during the design life of the pavement; and a stripping inflection point at around 1,300 passes indicted a severe stripping problem, which would limit the life of the pavement to less than 3 years.

The stripping slope is the number of wheel passes divided by the impression depth (mm), which is the inverse of the slope shown in Figure 6.75. The slope is estimated after the stripping point is evaluated. Decrease of the slope indicates increase of the stripping potential.

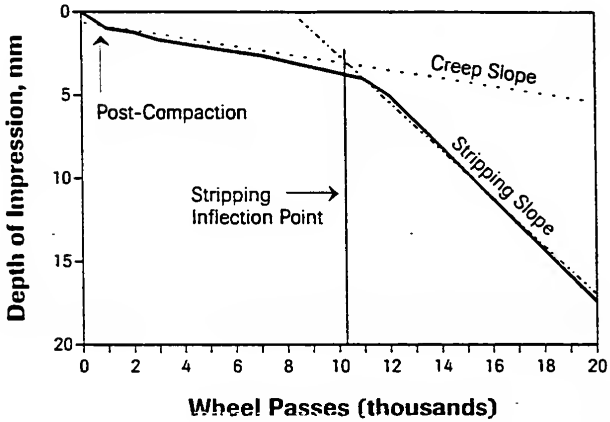


Figure 6.75 Relationship between Impression Depth and Number of Wheel Passes (After Elf Industires, 1992)

6.6.3 Stripping Inflection Point

Table 6.12 presents the summary of the stripping inflection points and the stripping slopes of the mixtures tested. As can be seen in Table 6.12, the stripping resistance improved with the inclusion of CB and PCB in AC-10 mixtures. As the CB and PCB were added to AC-10 mixtures, the stripping resistance increased. The CB mixture shows the best resistance against stripping. However, the stripping slope, which represents the sensitivity of stripping potential, is not increased as much as the stripping resistance. Figure 6.76 shows the comparison of the stripping resistance for each mixture.

The analysis of results of AC-20 mixtures tests shows that the inclusion of CB and PCB causes the stripping resistance to improve. The carbon black mixtures also show excellent stripping resistance in AC-20 mixtures. However, the improvement of the stripping resistance is more significant using AC-20 than AC-10 for both CB and PCB. Figure 6.77 shows the comparison of the stripping resistance for each mixture.

While the stripping inflection point is increased with the inclusion of PCB in both grades of asphalt mixtures, a significant decrease of the stripping potential is not obtained with the inclusion of the PCB. The CB mixture shows the same result on the stripping potential. Therefore, it is concluded that once the pavement has begun to strip, the stripping will continue and it is not easy to retard the propagation of the stripping.

As commercial carbon black is a hydrophobic material, antistripping action of the CB mixture is much more significant than other mixtures. A basic function of an antistripping agent is to counteract the hydrophilic aggregate surface and to make the

mixture resistant to stripping. Since PCB contains 75 % carbon black and only 25 % of other elements, it is expected that it will be an effective antistripping agent.

Table 6.12 The Summary of the Test Results for the Hamburg Wheel Tracking Device

Mixture	Stripping Slope	Stripping Inflection Point
AC-10	313.2	2,800
AC10 + 10 % CB	288	6,500
AC10 + 15 % CB	343.8	8,000
AC10 + 10 % PCB	277.8	3,000
AC10 + 15 % PCB	315.5	3,500
AC-20	626.4	7,100
AC 20 + 10 % CB	No Stripping	<20,000
AC20 + 15 % CB	No Stripping	<20,000
AC20 + 10 % PCB	624	7,200
AC20 + 15 % PCB	632.8	8,800

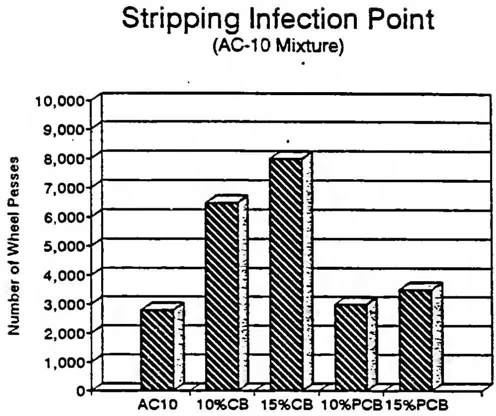


Figure 6.76 Comparison of Stripping Resistance (AC-10 Mixtures)

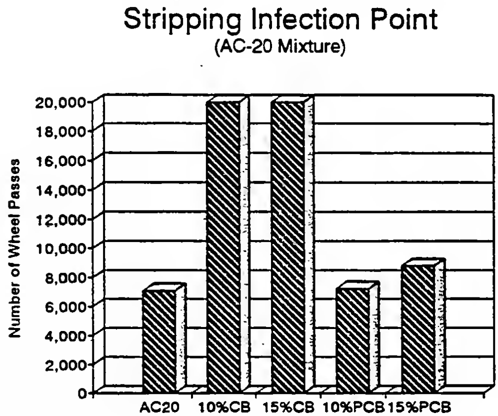


Figure 6.77 Comparison of Stripping Resistance (AC-20 Mixtures)

6.7 Indirect Tensile Testing

6.7.1 Test Results

The indirect tensile testing provides the tensile strength of the mixture, and the cracking potential of the mixture can be estimated through the tensile strength. The ultimate applied load at failure was obtained from the test and the tensile strength was calculated. The results of the indirect tensile testing for AC-10 and AC-20 mixtures are summarized in Table 6.13 and Table 6.14. The ultimate applied load were almost the same for each mixture type of asphalt. The AC-20 mixtures recorded the higher applied load as can be seen from the Tables.

Table 6.13 The Results of Indirect Tensile Testing for AC-10 Mixtures

Mixture	Ultimate Applied Load, KN	Tensile Strength, KPa
AC-10	24.3	2396
AC10 + 5% CB	24.0	2369
AC10 + 10% CB	24.3	2400
AC10 + 15% CB	24.4	2409
AC10 + 20% CB	24.0	2369
AC10 + 5% PCB	26.7	2636
AC10 + 10% PCB	23.7	2340
AC10 + 15% PCB	24.6	2429
AC10 +20% PCB	26.6	2626

Table 6.14 The Results of Indirect Tensile Testing for AC-20 Mixtures

Mixture	Ultimate Applied Load, KN	Tensile Strength, Kpa
AC-20	30.4	3001
AC20 + 5% CB	29.9	2952
AC20 +10% CB	30.5	3011
AC20 + 15% CB	31.1	3070
AC20 + 20% CB	27.8	2745
AC20 + 5% PCB	29.8	2942
AC20 + 10% PCB	29.2	2883
AC20 + 15% PCB	32.7	3228
AC20 + 20% PCB	32.3	3189

6.7.2 Test Data Analysis

The tensile strength of mixtures is calculated using the following equation:

$$S_T = \frac{2P_{ult}}{\pi t D} \tag{6.14}$$

where,

S_T = Tensile strength of mixture (KPa)

P_{ult} = Ultimate applied load at failure (N)

t = Height of specimens (mm)

D = Diameter of specimens (mm)

Figure 6.78 presents the tensile strength of both grades of mixtures versus PCB and CB content. The 15% and 20% PCB mixtures for AC-10 and AC-20 indicate an

increase in tensile strength, however, the increase is not significant. The tensile strength of both grades of asphalt mixtures appears to be essentially independent of the inclusion of PCB or CB.

Figure 6.79 and Figure 6.80 show the failure mode of the AC10 + 20% PCB mixture and AC20 + 20% PCB mixture, respectively. The failure mode is dependent on the characteristics of asphalt, which was observed from the creep test and the resilient modulus test. As seen in Figure 6.79 and Figure 6.80, the AC10 PCB mixture shows plastic behavior after the failure, while the AC-20 PCB mixture shows brittle failure.

Based on indirect tensile testing, it can be concluded that the inclusion of PCB in either grade of asphalt at low temperature does not enhance the tensile strength, while it has no adverse effect on the cracking potential of the conventional asphalt mixture. The indication of brittleness in the AC-20 mixture provides the higher tensile strength, however, the crack propagation in AC-20 mixtures could be more critical than in AC-10 mixtures due to sudden failure, with no healing action.

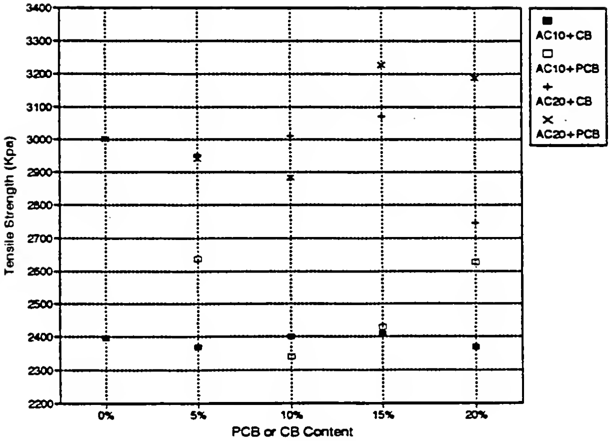


Figure 6.78 The Tensile Strength of the Mixtures

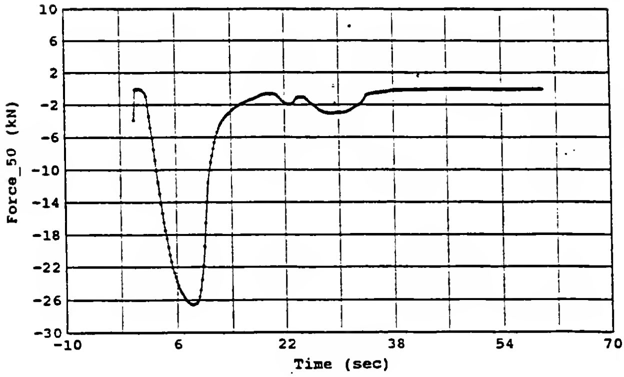


Figure 6.79 The Failure Mode of AC-10 + 20% PCB Mixture

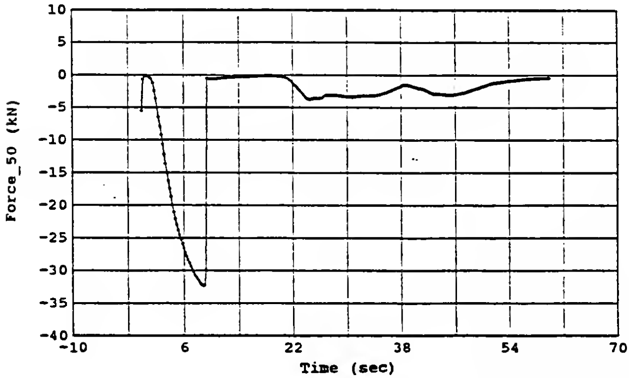


Figure 6.80 The Failure Mode of AC-20 + 20% PCB Mixture

6.8 Summary of Discussion

6.8.1 Marshall Test Method

The Marshall stability of the PCB mixtures is almost the same as that of the CB mixtures and the conventional mixtures at the optimum binder content. This trend appears to be maintained in both grades of asphalt mixtures. The most significant improvement of the PCB mixtures is that the rate of reduction of the Marshall stability with decreasing air voids is not as severe as that observed in the conventional mixtures. The same trend is observed with the CB mixtures, however, the rate of reduction of the stability is slightly higher than the PCB mixtures.

The void relationships, Voids in Total Mix (VTM), Voids in Mineral Aggregate (VMA), and Voids Filled with Asphalt (VFA) show a general agreement with those expected with the inclusion of most additives. The VTM and the VMA increase with increasing PCB and CB content. The VFA decreases with increasing PCB and CB content. The optimum asphalt content increases in AC-10 mixtures and decreases in AC-20 mixtures with increasing PCB and CB content. None of the Marshall parameters of the conventional mixtures indicate any significant improvement attributable to CB or PCB modification.

6.8.2 Gyratory Testing Machine

The Gyratory Testing Machine provides the characteristics of the asphalt mixtures as compaction proceeds. The Gyratory Compactibility Index (GCI), the Gyratory Stability Index (GSI), the Gyratory Shear (Sg), the Gyratory Shear Factor (GSF) are analyzed to investigate the effect of the use of PCB and CB.

The compactibility of PCB and CB mixtures is independent of the inclusion of PCB or CB in both grades of asphalt. The GCI of the PCB mixture is almost the same as that of the CB and the conventional mixtures. No adverse effect on the compaction is anticipated due to the inclusion of PCB.

The GSI, which is related to the plastic deformation of the conventional mixtures, indicates that the conventional mixtures show the most stable condition, however, the PCB mixtures are more stable and undergo less plastic deformation than the CB mixtures. The Gyratory Shear Factor (GSF) of the PCB mixtures shows performance superior to all other mixtures. When both GSI and GSF at high Gyratory revolutions are used to evaluate the performance of the mixtures, the 5 % and the 10 % PCB mixture for both grades of asphalt and both of the conventional mixtures indicate the potential for desirable performance and high shear resistance. Based on the analyses of the Gyratory Stability Index and Gyratory Shear Factor, two conclusions may be reached; 1) the inclusion of PCB in the asphalt mixture enhances the shear resistance of the pavement, and 2) the plastic deformation can be controlled by the appropriate amount of PCB used. Table 6.15 is a relative comparison of the test results of the Gyratory Testing Machine. The relative comparison is made in order to evaluate the effects of PCB and CB in both grades of asphalt. As shown in Table 6.15, the PCB mixtures generally exhibit better performance.

Table 6.15 The Effect of PCB and CB in AC-10 and AC-20 Mixtures.

	PCB Mixture		CB Mixture		Conventional Mixture	
	AC-10	AC-20	AC-10	AC-20	AC-10	AC-20
GCI	o	o	o	o	o	o
GSI	*	*	x	x	o	o
GSF	o	o	x	x	*	*
Sg	o	o	*	x	*	*

Note : o : Good, * : Reasonable, x : Poor

6.8.3 Rutting Resistance

The rutting resistance of the mixture can be evaluated by the creep test results. The test results are somewhat dependent on the characteristics of the asphalt. The AC-10 PCB and CB mixtures indicate an increase in rutting resistance. Both PCB and CB mixtures show almost the same increase in rutting resistance. The 15 % PCB mixture and the 20 % CB mixture exhibit the best potential for increasing the rutting resistance in the AC-10 mixture. A non-linear regression indicates that the creep potential of the AC-10 PCB mixture is less than either the CB mixture or the conventional mixture.

In contrast to the AC-10 conventional mixtures, resistance to rutting decreased with the inclusion of PCB and CB in the AC-20 mixtures. The rutting resistance of the AC-20 CB and PCB mixtures decreases with increasing CB and PCB content. Table 6.16 provides a summary of the rutting resistance for both grades of asphalt with inclusion of PCB and CB.

Table 6.16 The Summary of Rutting Resistance

	PCB Mixture	CB Mixture
AC-10	Increase	Increase
AC-20	Decrease	Decrease

6.8.4 Resilient Modulus

The resilient modulus of the mixture is tested at two different temperatures. (5°C and 25°C). The resilient modulus of the PCB mixtures is generally higher than that of the CB mixtures and the conventional mixtures. The resilient modulus is effected by both the asphalt type and the asphalt temperature. While the inclusion of PCB in the AC-10 mixtures tend to increase the resilient modulus at both low and high temperature, its inclusion in the AC-20 mixtures shows less improvement at low temperature, whereas there is a significant improvement at high temperature. While the inclusion of PCB or CB generally reduces temperature susceptibility, this effect is more advantageous when PCB is used. Table 6.17 shows the relative effect of PCB and CB in both grades of asphalt at two different temperatures, and shows that the PCB mixtures perform well at both low and high temperatures.

Table 6.17 The Effect of PCB and CB on the Resilient Modulus

	PCB Mixture		CB Mixture		Conventional Mixture	
	5°C	25°C	5°C	25°C	5°C	25°C
AC-10	o	o	*	*	x	x
AC-20	*	o	o	*	*	x

Note : o : Excellent, * : Good, x : Fair

6.8.5 Stripping Resistance

The stripping resistance of the mixture is evaluated from the Hamburg Wheel Tracking Device. Stripping resistance increases with increasing PCB and CB content in both AC-10 and AC-20 mixtures. While the CB mixtures demonstrate the best overall resistance to stripping, the rate of improvement in stripping resistance with increasing CB content is more significant in the AC-20 mixtures. In particular, both 10% and 15% CB mixtures show high stripping resistance. Table 6.18 shows the relative effect of PCB and CB in both grades of asphalt mixtures for stripping resistance.

Table 6.18 The Effect of PCB and CB on the Stripping Resistance

	PCB Mixture	CB Mixture	Conventional Mixture
AC-10	*	o	x
AC-20	*	o	x

Note : o : Excellent, * : Good, x : Poor

6.8.6 Cracking Potential

Indirect Tensile Testing provides a measure of the cracking potential of the mixtures. The inclusion of PCB and CB in both grades of asphalt at low temperature (5°C) does not enhance the tensile strength significantly, while it has no adverse effect on the cracking potential of both grades of the conventional asphalt mixtures.

Though increase of the tensile strength is not significant for all mixtures, in general, the PCB mixtures indicated the best performance, the use of 10 percent by weight of asphalt could be considered optimum to decrease the cracking potential. On the other hand, the CB mixtures show better behavior than the conventional mixtures.

6.8.9 Material Cost Comparison

The raw material cost of the commercial carbon black is 71 cents/lb (CABOT, 1995) and the pyrolized carbon black is 16 cents/lb (Wolf Industries, 1995). Table 6.19 shows the raw material cost of the commercial carbon black and the pyrolized carbon black. The raw material cost can be reduced as much as $1100/ton by using PCB as compared to when CB is used as an additive.

Table 6.19 The raw material cost for CB and PCB

	Commercial Carbon Black (High Structure HAF Type)	Pyrolized Carbon Black (Not Mill Ground)
Material Cost	71 cents/lb ($1420/ton)	16 cents/lb ($320/ton)

Note : 1) The raw material cost provided by the manufacturer.
2) The price does not include shipping costs.

If a 5 mile, two lane road is overlaid to a depth of 1.5 inch with optimum asphalt content at 5 %, approximately 300 tons of asphalt binder are needed. Therefore, 15 tons of PCB or CB are required for a 5 % mixture, 30 tons for a 10% mixture, 45 tons for a 15% mixture and 60 tons for a 20% mixture. When a 10% mixture is used for the pavement construction, approximately 30 tons of PCB or CB are needed to blend with the asphalt. Figure 6.81 shows the comparison of the raw material cost for the complete mixture in the case of 10% PCB and 10% CB mixture. As can be seen in the cost comparison, the raw material cost can be reduced significantly by using PCB compared to using CB. The cost to use pyrolized carbon black can potentially be compensated by extending the service life of the pavement and a better quality of the pavement condition. However, this can only be verified through the field trials.

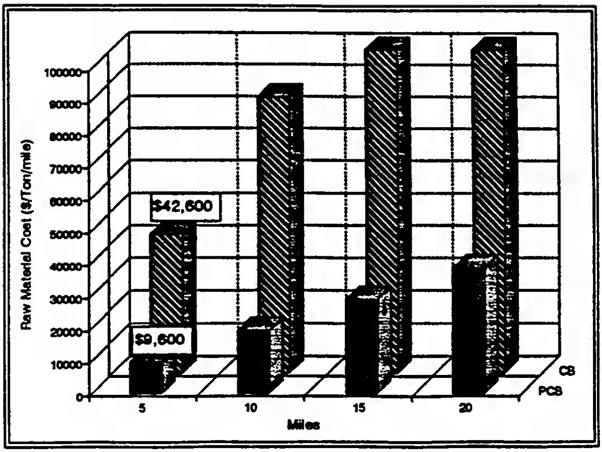


Figure 6.81 The Comparison of the Raw Material Cost for 10% PCB and CB

Note :1) Raw Material Costs (Keiser & Keiser Contractors Inc., 1995)

a) AC-10 and AC-20 : $126/ton (Varies everyweek)

b) #9 Binder Mix : $21.75/ton

c) PCB : $320/ton, CB : $1,420/ton

2) Construction Cost : 5 miles, 1.5 inch thick, 2 lanes

a) 5 miles × 5280 ft/mile × 24 ft (2 lanes) × 1.5/12 = 79,200 ft^3

b) G.S for the Asphalt Mixture (2.4) × 62.4 lb/ft^3 = 149.76 lb/ft^3

c) 149.76 lb/ft^3 × 79,200 ft^3 = 11,860,992 lb (6000 tons)

d) Assumed the optimum binder content to be 5 % :

- Asphalt needed : 6000 tons × 0.05 = 300 tons
- Using 10 % PCB or CB: 300 tons × 0.1 = 30 tons

3) Raw Material Costs

a) Asphalt Mix : 6000 tons × $21.75/ton = $130,500

b) PCB : 30 tons × $320/ton = $9,600 (7.3 % Increase)

c) CB : 30 tons × $1,420/ton = $42,600 (32.6 % Increase)

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study, based on comprehensive laboratory testing and evaluations, assesses the usefulness and feasibility of using pyrolized carbon black from waste tires in hot mixed asphalt. The characteristics and performance of the pyrolized carbon black (PCB) modified asphalt concrete are investigated and compared to the carbon black (CB) modified asphalt and the conventional asphalt concrete. The Marshall Test Method, the Gyratory Testing Machine (GTM), the Dynamic Creep Test, the Hamburg Wheel Device, the Resilient Modulus Test, and the Indirect Tensile Test were performed.

The complete behaviors of PCB modified asphalt concrete were investigated. The performance of PCB modified asphalt concrete at low temperature (5°C) was defined by the Indirect Tensile Test which provided the cracking potential of the mixture. The performance at mid-temperature ranges (5°C to 25°C) was investigated by the Resilient Modulus Test which gives the strength of the PCB mixtures. The creep behavior was investigated by the Dynamic Confined Creep Test at 50°C to investigate the rutting potential of the PCB mixtures. The mechanical properties and the optimum binder contents were determined by the Marshall Test results. The stress-strain behavior of the PCB modified asphalt concrete was determined by the Gyratory Testing Machine. In

addition, the Hamburg Wheel Tracking Device was employed to define the stripping potential of the PCB mixture. The findings of this study demonstrate the beneficial effect of PCB additives on the conventional asphalt mixtures.

7.2 Conclusions

It has been shown that pyrolized carbon black (PCB) from scrap tires is useful as a reinforcing agent in asphalt mixtures. Based on the laboratory testing programs in this study, the following principal conclusions can be drawn:

1) The performance and characteristics of PCB modified asphalt concrete are somewhat dependent on the characteristics of the asphalt. The use of PCB in AC-10 asphalt mixtures provides more benefits than in AC-20 asphalt mixtures.
2) At optimum binder content, the Marshall stability of the PCB modified asphalt concrete is less sensitive to the degree of compaction (Air Voids).
3) Compactibility of the PCB mixture is independent on the inclusion of PCB. Gyratory Stability Index (GSI) increases with the PCB content in the AC-10 mixtures and the AC-20 mixtures, except for the AC20 + 20% PCB mixture. The inclusion of PCB in both grades of asphalt mixtures improves the shear resistance of the pavement, and the plastic deformation can be controlled by the appropriate amount of PCB.

4) Rutting potential is reduced with increasing PCB content in AC-10 mixtures.

5) Less stripping potential is to be expected in both grades of PCB asphalt mixtures.

6) The temperature susceptibility at high temperature is decreased by the inclusion of PCB, without affecting the resilient modulus at low temperatures.

7) The increase of tensile strength due to the inclusion of PCB is not significant for either grade of asphalt. Thus the tensile strength is independent of the inclusion of PCB.

8) The typical performance of PCB modified asphalt mixtures is improved with respect to CB modified mixtures and conventional asphalt mixtures.

9) A pyrolized carbon black content of 10 % to 15 % by weight of asphalt is recommended for the improvement of the asphalt concrete.

7.3 Recommendations

While the laboratory test results have shown performance improvement of PCB modified asphalt, some problems associated with the use of PCB from scrap tires as a reinforcing agent are anticipated. One problem is in the handling of loose PCB in the field; another is achieving dispersion of the PCB in asphalt.

1) Additional laboratory studies should include use of slag aggregate, and changes in the characteristics of the asphaltic binder when PCB is added.

2) Mixing technology of PCB in asphalt should be studied in the laboratory prior to further attempts in the field.

3) Test sections should be planned for 1996 or 1997, using the mixtures which have been shown to be most effective in the laboratory.

4) Rheological study of PCB modified asphalt cement will provide fundamental understanding of the effects of PCB behavior on different characteristics of asphalt.

5) Reuse and recycling of pyrolized carbon black asphalt concrete should be considered and studied.

LIST OF REFERENCES

LIST OF REFERENCES

Notes :

AAPT :	Association of Asphalt Paving Technologists
ASCE :	American Society of Civil Engineering
DOT :	Department of Transportation
ENR :	Engineering News Record
JHRP :	Joint Highway Research Project
FHWA :	Federal Highway Administration
NAPA :	National Asphalt Pavement Association
OECD :	Organization for Economic Cooperation and Development
TRB :	Transportation Research Board

References Cited

Ahmed, I (1993), "Laboratory Study on Properties of Rubber Soils," Ph.D Thesis, West Lafayette, Purdue University

Ahmed, I. (1991), "Use of Waste Materials in Highway Construction," Report No. FHWA/IN/JHRP-91/3, School of Civil Engineering, Purdue University, West Lafayette, Indiana, 112 pp.

Ahmed, I. and Lovell, C.W. (1992), "Use of Waste Materials in Highway Construction: State of the Practice and Evaluation of the Selected Waste Products," Soils, Geology, and Foundations: Geoenvironmental and Engineering Properties of Rock, Soil, and Aggregate, TRB, Transportation Research Record No. 1345, National Research Council, pp. 1-9.

Allen, H. S. and Turgeon, C. M. (1990), "Evaluation of PlusRide," Report No. 90-01, Minnesota DOT, Maplewood, MN, 35 pp.

Alliotti, A. G. (1962), "Carbon Black - Its Nature and Possible Effects on the Characteristics of Bituminous Road Binders," Proceedings Australian Road Research Board, Vol. 1, Part 1.

Anderson, E. V. (1972), Chemistry Engineering News, Vol. 50(33), No. 8.

Aschenbrener, T.(1993), "Influence of Testing Variables on the Results from the Hamburg Wheel Tracking Device", Colorado Department of Transportation, CDOT-DTD-R-93-22, Final Report, December 7, 35 pp.

Aschenbrener, T., Terrel, R. L., Zamora, R.(1994), "Comparison of the Hamburg Wheel Tracking Device and the Environmental Conditioning System to Pavements of Known Stripping Performance", Colorado Department of Transportation, CDOT-DTD-R-94-1, Final Report, January, 44 pp.

Asphalt Institute (1994), "Mix Design Methods for Asphalt Concrete and Other Hot Mix Types," MS-2, Sixth Edition, Kentucky.

Audeoud, B., Bailly, J. C., Jean, P. A., Lareal, P., Long, N.T., Ursat, P., and Valeux, J.C. (1990), "The Pneusol," Laboratorie Central des ponts et Chaussees, IST - Section des publications, Paris, France, 76 pp.

Augeri, F. (1986), "Placement of Experimental Bituminous Concrete Mixture Utilizing an Asphalt Additive - Carbon Black," Connecticut Department of Transportation, Bureau of Highway, HPR-1085, Wethersfield, Connecticut.

Beckman, J. A. (1974), "Geosynthetics as Earth Reinforcement," Geotechnical Fabrics Report, Vol. 9, No. 5, pp. 44 - 46.

Boicycle (1989), "Recycled Rubber Roads," Biocycle, Vol. 30, No. 2.

Brown, E. R., Collins, R. and Brownfield, J. R. (1989), "Investigation of Segregation of Asphalt Mixtures in the State of Georgia," TRB Transportation Research Record No. 1217, National Research Council, Washington, D. C..

Brown, E. R. and Cross, S. (1989), "A study of In-Place Rutting of Asphalt Pavements," Proceedings, AAPT, Vol. 58.

Brown, E.R. and Foo, K.Y. (1994), "Comparison of Unconfined and Confined Creep Tests for Hot Mix Asphalt," ASCE, Journal of Materials in Civil Engineering, Vol.6, No, 2, May, 307 - 326 pp.

Button, J. W. and Little, D. N. (1988), "Additives Have Potential to Improve Pavement Life," Road & Bridge, January, pp. 76 - 80.

CABOT Industries (1994), "Carbon Blacks for Specialty Applications", CABOT Corporation Special Blacks Division, Catalogue, Massachusetts.

CABOT Industries (1995), Telephone Conversation with Christ Cornille on Raw Material costs of High Structure HAF Type

Caltrans (1988), "Use of Discarded Tires in Highway Maintenance," Translab Design Information Brochure No. TL/REC/1/88, Sacramento, CA (Unpublished).

Cindy, K., Button, J. W. and Fernando, E. G. (1990), "Use, Availability, and Cost-Effectiveness of Asphalt-Rubber in Texas," Report No. Tx91/1902-1F, Texas State Department of Highways and Public Transportation, Transportation Planning Division, Austin, Texas, 108 pp.

Elf Industries (1992), "Hamburg Wheel Tracking Device", Technote, Catalogue.

Engineering Developments Company Inc. (1993), "Gyratory Testing Machine Preparation and Maintenance Manual," EDCI, Mississippi.

EPA (1991), "Markets for Scrap Tires," Report No. EPA/530-SW-90-074A, United States Environmental Protection Agency, Office of Solid Waste, Washington, D.C., 115 pp.

Finn, F. N. (1967), "Factors Involved in the Design of Asphaltic Pavement Surfaces," HRB, NCHRP Report 39.

Finn, F. N., Monismith, C. L., and Markevich, N. J. (1983), "Pavement Performance and Asphalt Concrete Mix Design," Proceedings, AAPT, Vol. 52.

Ford, M. (1988), "Pavement Densification Related to Asphalt Mix Characteristics." TRB, Transportation Research Record 1207, Washington D.C..

Foster, T. W. (1990), "Evaluation of Carbon Black Experimental Construction B4-02," Maine Department of Transportation, Augusta, Maine, August.

Forsyth, R. A. and Egan, J. P. (1976), "Use of Waste Materials in Embankment Construction," TRB, Transportation Research Record, Vol. 593, pp. 3 -8.

Gabrielson R.J.(1992), "Evaluation of Hot Mix Asphalt (HMA) Static Creep and Repeated Load Tests", Ph.D. Dissertation, Auburn University, Alabama, December 16, 219 pp..

Habermann, J. A. (1994), "Design Features and a Preliminary Study of the Purdue Linear Compactor and the Purwheel Tracking Device," M.S. Thesis, Purdue University, West Lafayette, Indiana.

Hare, B. (1990), "A Field Study on Carbon Black Modified Pavement," Pennsylvania Department of Transportation.

Heitzman, M. (1992), "An Overview of Design and Construction of Asphalt Paving Materials with Crumb Rubber Additives," TRB, Transportation Research Record 1318, Washington D.C..

Hills, J. F. (1973) "The Creep of Asphalt Mixes," Journal of the Institute of Petroleum, Vol. 59, No. 570, London, England.

Hills, J. F., Brein, D., and Van de Loo, P. J. (1974) "The Correlation of Rutting and Creep Tests on Asphalt Mixes," Paper IP 74001, Institute of Petroleum, London, England, January

Hines, M. (1991), "The Hamburg Wheel Tracking Device," Proceedings of the Twenty Eighth Paving and Transportation Conference, Civil Engineering Department,TheUniversity of New Mexico, Albuquerque, New Mexico.

Huber, G. A. and Herman, G. H. (1987), "Effect of Asphalt Concrete Parameters on Rutting Performance: A Field Investigation," Proceedings, AAPT, Vol.56.

Indiana Department of Highway Specifications (1993), Indiana Department of Highways, Indianapolis, Indiana.

Kandhal, P. S. and Koehler, W. C. (1986), "Significant Studies on Asphalt Durability: Pennsylvania Experience." TRB, Transportation Research Record 999.

Keiser & Keiser Contractors Inc. (1995), Telephone Conversation with Tom on April 15, 1995.

Khedaywi, T.S. (1988), "Effect of Inclusion of Oil Shale Ash on Behavior of Asphalt Concrete", TRB, Transportation Research Record 1171, Washington D.C. pp.1 - 7.

Khosla, N. P. (1991), "Effect of the Use of Modifiers on Performance of Asphatic Pavements," TRB, Transportation Research No. 1317, Washington D.C., pp. 10 - 22.

Kim, Y.R., Khosla, N.P., Kim, N.(1991), "Effect of Temperature and Mixture Variables of Fatigue Life Predicted by Diametral Fatigue Testing", Transportation Research Record 1317, TRB, National Research Council Washington D.C., pp.128 - 137.

Lohrey, C. E. (1991), "Field Evaluation of an Experimental Bituminous Pavement Utilization an Asphalt Additive - Carbon Black," State of Connecticut Department of Transportation, Report No. 1085-3-91-6, Rocky Hill, Connecticut, 29 pp. July.

Maine Department of Transportation (MEDOT), (1992), "Evaluation of Gyratory Testing Machine Mixture Design Results for Work Performed in 1991", Research Report No. Problem Solving 92-21.

Martin, K. G. (1962), "Preliminary Microviscometer Studies of Carbon Black (Rubber) Bitumen Dispersions," Proceedings Australian Road Research Board, Vol.1, Part 1, pp. 895.

McQuillen, J. L. and Hicks (1987), "Construction of Rubber Modified Asphalt Pavements, Journal of Construction Engineering and Management, Vol. 133, No.4 pp. 537-553.

McRae, J.L.(1993), "Gyratory Testing Machine Technical Manual", Engineering Developments Co. Inc., Mississippi, 103 pp..

MTS Corporation (1994), "Operation Manual for Material Testing System", Material Testing System Incorporation, Minnesota, Minneapolis.

OECD (1981), "Used Tires in Solid Waste Management," Organization for Economic Cooperation and Development (OECD), Paris, France, 95 pp.

Perl, M., Uzan, J., and Arieh, S. (1983), "Visco-elasto-plastic Constitutive Law for a Bituminous Mixture under Repeated Loading," TRB, Transportation Record 911, Washington D.C. pp 20 - 27.

Powell, R. (1968), "Carbon Black Technology Recent Developments," Chemical Process Review, No. 21, Park Ridge, N. J., Noyles Development Corp.

Raven, E. (1987), "Method and Material for Crack Reflectance," Minnesota Department of Transportation.

Robert, F.L., Kandhal, P.S., Brown, E.R., Lee, D.Y. and Kennedy, T.W. (1991), "Hot Mix Asphalt Materials, Mixture Design and Construction" 1st Edition, The National Asphalt Pavement Association (NAPA) Education Foundation, Lanham, Maryland.

Rostler F.S., White, R.M. and Dannenberg, E.M. (1977), "Carbon Black as a Reinforcing Agent for Asphalt", AAPT, Vol. 46, pp. 376 - 401.

Roy, C., Labrecque, B., and Caumia de, B. (1990), "Recycling of Scrap Tires to Oil and Carbon Black by Vacuum Pyrolysis," Resources, Conservation and Recycling, No.4. pp.203 - 213.

Ruth, B. E. (1991), "Evaluation of Ground Tire Rubber in Asphalt Concrete," Department of Civil Engineering, University of Florida, Gainesville, Floroda.

Santucci, L. E., Allen D.D. and Coats, R. L. (1985), "The Effects of Moisture and Compaction on Quality of Asphalt Pavements." Proceedings, AAPT, Vol.54.

SHRP (1994), "The SUPERAVE Mix Design System Manual of Specifications, Test Methods, and Practices:, Strategic Highway Research Program," SHRP-A-379, National Research Council, Washington DC., 125 pp.

Takallou, H. B. and Hicks, R. G. (1988), "Development of Improved Mix and Construction Guidelines for Rubber Modified Asphalt Pavements'" TRR, No. 8, pp. 1023 - 1927.

U. S. Army Corps of Engineers (1962), "Development of The Gyratory Testing Machine and Procedures for Testing Bituminous Paving Mixtures", Technical Report No. 3-595, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 34 pp..

U. S. Army Corps of Engineers (1962), "Gyratory Compaction Method for Determining Density Requirements for Subgrade and Base of Flexible Pavements", Miscellaneous Paper No. 4-494, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. 9 pp..

U. S. Army TM 5-822-8 (1987), "Bituminous Pavements Standard Practice," Technical Manual, Department of the Army.

Vallerga, B.A. and Gridley, P.F. (1980), "Carbon Black Reinforcement of Asphalt in Paving Mixtures", Asphalt Pavement Construction, New Materials and Techniques, ASTM STP 724, J.A. Scherocman, Ed., American Society for Testing and Materials, pp. 110 - 128.

Van der Poel, C. (1954), "A General System Describing the Viscoelastic Properties of Bitumens and Its Relation to Routine Test Data," Journal of Applied Chemistry, Vol.4, May.

Von Quintus, H.L., Scherocman, J.A., Hughes, C.S. and Kennedy, T.W.,(1991), "Asphalt-Aggregate Mixture Analysis System (AAMAS). National Cooperative Highway Research Program Report 338, TRB, National Research Council, Washington, D.C.

Wahhab, H. A. and Khan, A. Z., (1991) "Evaluation of Marshall and Hveem Mix Design Procedures for Local Use," Transportation Research Record, No. 1317, TRB, National Research Council, Washington, D. C.

Wolf Industries (1994), "Product Specification Data and Material Safety Data Sheet,", Personal Letter from Mr. Foster.

Wolf Industries (1995), Telephone Conversations with Mr. Foster on Raw Material Costs of Pyrolized Carbon Black.

Yao, Z. and Monismith, L. C. (1986), "Behavior of Asphalt Mixtures with Carbon Black Reinforcement", AAPT, Vol.55, pp.564 - 585.

Zhang, X., Gress, D. and Eighmy, T., (1994) "Bottom Ash Utilization as an Aggregate Substitute in Hot Mix Asphalt" Proceedings of the 2nd Annual Great Lakes, Goetechnical/Geoenvironmental Conference, May 20, 1994, Purdue University, West Lafayette, Indiana.

Zube, E. (1962), "Compaction Studies of Asphalt Concrete Pavement as Related to the Water Permeability Test," Highway Research Board, Bulletin 358, Washington D.C., pp.12 - 37.

Other References

Ahmed, I. (1992), "Laboratory Study on Properties of Rubber Soils - Interim Report," Report No. FHWA/IN/JHRP-92/11, School of Civil Engineering, Purdue University, West Lafayette, Indiana, 145 pp.

Ahmed, I. and Lovell, C.W. (1993), "Use of Waste Materials in Highway Construction : State of the Practice and Evaluation of the Selected Waste Products," TRB, Transportation Research Record 1345, Washington D.C., pp. 1 -9.

Elliott, P. R., Ford Jr., C. M., Ghanim, M. and Tu, Y. F. (1991), "Effect of Aggregate Gradation Variation on Asphalt Concrete Mix Properties," TRB, Transportation Research Record 1317, Washington D.C..

George, K.P.(1992), "Resilient Testing of Soils Using Gyratory Testing Machine", TRB Transportation Research Record No. 1369, Washington D.C..

Kallas, B.F.(1965), "Gyratory Testing Machine Procedures for Selecting the Design Asphalt Content of Paving Mixtures", Proceedings, AAPT, Vol. 34

Kandhal, P. S. and Koehler, W. S. (1985), "Marshall Mix Design Method: Current Practices." Proceedings, AAPT, Vol. 54.

Kandhal, P. S. and Wenger, M. E. (1975) ,"Asphalt Properties in Relation to Pavement Performance." Transportation Research Record 544, TRB.

Kennedy, T. W. Hass, R. and Meyer, F.R. (1975), "Characterization of Pavement Materials for Fundamental Structural Analysis." Inter-American Conference on Materials Technology, Caracus, Venezuela.

Pink, S. H., Merz, E. R. and Bosnick, S. D. (1980), "Asphalt Rheology: Experimental Determination of Dynamic Moduli at Low Temperature", AAPT. Vol. 49, pp.64 - 94.

Rand, D. (1992), "Comments About Use and Results of Corps of Engineers Gyratory Testing Machine." Personal Letter by Zhang, Maine Department of Transportation.

Ruth, B. E. and Schaub, J.H. (1966), "Gyratory Testing Machine Simulation of Field Compaction of Asphaltic Concrete." Proceedings, AAPT, Vol. 35.

Ruth, B.E., Shen, X., Wang, L.H., (1992) "Gyratory Evaluation of Aggregate Blends to Determine Their Effect on Shear Resistance and Sensitivity to Asphalt Content," ASTM STP 1147, American Society for Testing and Materials, Philadelphia.

Traxler, R. N. (1963) "Durability of Asphalt Cements." Proceedings AAPT, Vol. 32.

Turgeon, C. M. (1989), "The Use of Asphalt-Rubber Products in Minnesota," Report No. 89-06, Minnesota DOT, MN, 11 pp.

Vallerga, B. A., Monismith, C. L. and Granthem, K. (1957), "A study of Some Factors Influencing the Weathering of Paving Asphalt." Proceedings AAPT, Vol.26.

White, T.D. (1985), "Marshall Procedures for Design and Quality Control of Asphalt Mixtures," Proceedings, AAPT, Volume 54.

APPENDIX A

Summary of Carbon Black Studies

Summary of Laboratory Studies

Selected laboratory studies are summarized. The purpose of the laboratory studies is to review the test methods, the test protocol and the effects of carbon black in asphalt mixtures.

Title: EFFECT OF THE USE OF MODIFIERS ON PERFORMANCE OF ASPHALTIC PAVEMENTS (TRB RECORD 1317,1991)

Author : N. Paul Khosla

This paper discussed the effect of two commercially available asphalt modifiers in improving the mechanical properties of asphalt paving mixtures. The author evaluated the abilities of these modifiers to mitigate pavement distress and improve overall pavement performance.

The test results show that the effect of the modifier on the paving mixture properties is pronounced at high temperatures. Carbon black is the most significant in reducing pavement rutting. Carbon black modifier shows a degree of improvement in the overall pavement performance.

Material Used and Specimen Preparation

1) The base asphalt used : AC-5, AC-10 and AC-20
2) Additives : Polymer and Carbon Black (Microfil8-pelletized carbon black using 8 percent maltenes.) Each modified asphalt was premixed.
3) AC-5 was blended with 12 % Microfil 8 and AC-10 with 10 % Microfil8.
4) Aggregate :Dense-graded aggregate was used. North Carolina 1-1 mix specifications were used.

5) The mixtures were designed in accordance with the Marshall method of mix design. The binder contents used in the mixtures were varied to keep the volume of the binder constant in all mixtures,

Testing Programs and Results

Creep test, fatigue, and resilient modulus tests were performed and compared with the conventional asphalt.

1) Creep test

Incremental static creep tests were performed on specimens 4 in. in diameter and 8 in. high to determine the permanent deformation coefficients to be used in the VESYS computer program. Test specimens at temperatures of -20, 0, 20, 40, 70, 90, and

120°F were tested under a creep stress of 20 psi. However, specimens at 140°F were tested under a creep stress of 10 psi due to the potential breakage of specimens.

The analysis of test results reveals that the mixtures containing the conventional asphalt AC-5, AC-10, and AC-20 exhibited significantly higher deformation than the mixtures modified with polymer and carbon black.

2) Resilient Modulus Test

The resilient modulus tests were conducted on 2.5 in. diameter and 4 in. high specimens in the indirect tension mode at the various temperatures (0, 40, 70, 100, and 140°F). Poisson's ratio was assumed to be 0.35.

The analysis of the test results show that adding carbon black to the asphalt reduces the temperature susceptibility and gives mixtures a higher resilient modulus at high temperatures without affecting the modulus values at low temperatures.

3) Fatigue Test

Fatigue response of the mixtures was measured on diametral specimens in the indirect tension mode. The controlled stress mode of loading with a square waveform was used, which included a 0.1 sec loading period and 2.9 sec unloading period. Stresses in the range of 15 to 50 psi were used, and the tests were conducted at 70°F. The test results show that mixtures containing AC-5 and AC-10 have relatively shorter fatigue lives than other mixtures.

<u>Conclusions</u>

Modifying asphalt with polymer or carbon black reduces :

a) the temperature susceptibility of the binders;
b) low-temperature cracking compared to conventional asphalt;
c) the permanent deformation of the paving mixtures at high temperatures and thus reduces the potential for rutting.

Title : BEHAVIOR OF ASPHALT MIXTURES WITH CARBON BLACK REINFORCEMENT (APT, Vol., pp564-585, 1986)

Authors : Zukang Yao and Carl L. Monismith

The authors tested to verify the effectiveness of carbon black in improving properties of asphalt concrete. The temperature-viscosity susceptibility, the rutting resistance at high temperature, the cracking resistance at low temperature were investigated by the inclusion of carbon black in asphalt mixtures. The experimental works included:

(1) Performance of uniaxial creep tests at high temperatures (55, 80, 110, 150°F).
(2) Conduct of flexural fatigue tests on beam specimens.

(3) Structural analyses of representative pavement sections to assess the influence of carbon black reinforcement on mixture performance.

(4) Determination of the tensile strength and stiffness of asphalt concrete reinforced with carbon black at low temperatures.

Materials Used

1) Aggregates

Dense graded asphalt concrete with two types of aggregate, granite and gravel, were used in the study. The gradation of the aggregates conforms to the State of California specifications.

2) Asphalt Cement

AR-2000, AR-4000, and AR-8000 were used in this study.

3) Carbon Black

The pelletized carbon black, Microfil 8, was blended with the AR-2000, in four proportions by weight; 5:95, 10:90, 15:85, and 20:80.

Specimen Preparation

1) Mix Design

Hveem stabilometer tests were performed on specimens containing the AR-4000 and the granite aggregate and on specimens with the AR-8000 and the gravel aggregate.

2) Creep test

Specimens for the creep test, about 4 in. (101.1 mm) in diameter and 9 in. (228.6) high, were prepared using the Triaxial Institute kneading compactor.

3) Fatigue test

Beam specimens for fatigue tests were also prepared using kneading compaction in mold 15 in. (381 mm)long and with a cross section of 3.5 in.x4.5 in. (88.9 mm x 114.3 mm).

Test Procedures and Results

1) Creep Test
The unconfined creep test was performed at different temperatures (0, 30, 55, 80, 110, 150° F).

Test results show that at low temperatures the creep characteristics of mixtures with carbon black reinforced AR-2000 were the same as the creep response of the mixes with AR-2000 asphalt. At high temperatures, the creep characteristics at long loading times of the mixes with carbon black reinforced AR-2000 asphalt were improved over mixes containing the AR-8000 asphalt. Generally, creep curves for specimens with carbon black microfiller exhibited less of a change in creep modulus with time than specimens without microfiller.

2) Fatigue

Fatigue response of asphalt mixtures with microfiller was measured in bending in the controlled stress mode of loading. Stress in the range 30 to 50 psi (206.7 to 1033.5 Mpa) were utilized. Load was applied for a duration of 0.1 second and repeated 100 times per minute. A stiffness modulus for each beam was determined from the center deflection measured after 200 repetitions by means of an LVDT. All tests were performed at a constant temperature of 68° F (20°C).

Test results showed that little difference exists between the fatigue response of asphalt concrete with and without carbon black.

3) Indirect Tension Test

Indirect tensile tests were performed on cylindrical specimens 4 in. in diameter and 2 to 2.6 in. height to determine the tensile strength of asphalt concrete with AR-2000, AR-8000, and AR-2000 plus 20 percent microfiller at three low temperature conditions; -20, 0, 20°F. Prior to testing, each specimen was kept for 24 hours in a cabinet at the specified test temperature. Loads to failure were applied at a rate of 0.025 in. per minute.

Results for the three mixes are about the same in the lower temperature range examined. The data suggest, as do the lower temperature stiffness data, that mixes with the carbon-black reinforced asphalt exhibit approximately the same low temperature response characteristics as do the specimens containing the AR-2000 without microfiller. Such response is desirable to mitigate low temperature cracking due to thermal stresses.

Summary of Study

Test results reveal that 15 to 20 % Microfil 8 (carbon black) by weight of the binder reduce the effect of temperature.

Creep test results show that a comparatively soft asphalt may be used to mitigate low temperature cracking yet provide improved resistance to rutting at high pavements temperatures.

The fatigue resistance and fracture strength were not adversely affected by the inclusion of carbon black microfiller.

Title :CARBON BLACK REINFORCEMENT OF ASPHALT IN PAVING MIXTURES (ASTM, SPT.724, 1980)

Authors : B.A. Vallerga and P. F. Gridley

This paper discussed the advantages of using carbon black in binder and asphalt concrete. Dispersion of submicrometer-size carbon black particles in asphalt at contents of 11 to 16 percent by weight of asphalt has been found to improve the asphalt properties of durability, wear resistance, and temperature-viscosity susceptibility.

Effects of the carbon black addition on the properties of asphalt and asphalt concrete, as measured in both laboratory and field experiments, are discussed.

Function of Carbon Black Filler

1) Effect on Asphalt Properties

The effects of the carbon black filler on the properties of a given asphalt will vary somewhat depending on the characteristics of the asphalt and the grade and dosage of the filler pellets. In general, the filler has been found to increase asphalt durability and decrease temperature-viscosity susceptibility.

2) Temperature-Viscosity Susceptibility

The test result of 21.2 percent of Microfil 25 by weigh of asphalt produced the following changes:

(a) At low temperature (0 to 39.2° F) - reduces the viscosity of both the 85 to 100 and 150 to 200 penetration grades. Little change was observed in 300 to 400 grade.

(b) At high temperature (95 to 140° F) - increase viscosity a full order of magnitude. (10 fold)

An amount of 21.2 percent of Microfil 8 to the 300 to 400 penetration asphalt showed the following changes:

(a) At low temperature - essentially no change
(b) At high temperature - essentially a 50 fold increase in viscosity

An examination of these data reveals that, in all cases, the temperature-viscosity susceptibility of these carbon black-reinforced grades of this asphalt is markedly reduced.

Effects on Asphalt Concrete Properties

The observation of the field and laboratory revealed a significant increase of the strength and wear resistance by the use of carbon black in asphalt mixtures.

Additionally, the increase of low temperature cracking resistance and high temperature distortion resistance of the asphalt mixture have been found to be produced by the inclusion of carbon black.

1)Strength

An asphalt binder reinforced with carbon black provides greater resistance because the carbon black particles stiffen the asphalt. Test results obtained on specimens tested for strength by the conventional Hveem Cohesionmeter and Marshall load tests are generally higher with the carbon-reinforced asphalt. The strength determined by the Marshall load test has been increased about 40 percent.

2) Wear Resistance

Wear resistance effect was monitored by the visual observation in the field. The observation data revealed that there was significantly less wear in the carbon black section than in the conventional section.

3) Resistance to Low -Temperature Cracking

The addition of carbon black filler has been found to increase the stiffness of the asphalt at high temperature while essentially not affecting its low-temperature stiffness characteristics.

4) Resistance to High Temperature Distortions

The inclusion of carbon black in asphalt can provide a more appropriate approach for mitigation of rutting and early embrittlement of the pavement. The use of soft grade asphalt (over 200 penetration) to accommodate the low-temperature problem, benefits from carbon black filler added to impart greater stiffness to the binder over the high-temperature range of exposure.

Conclusions

1) High structure HAF type carbon black has a beneficial effect on the durability, wear resistance, and temperature-viscosity susceptibility.

2) The pelletized carbon black serves as a proper dispersal of carbon black particle in asphalt.

3) The asphalt concrete properties can be adjusted within certain limit by the judicious selection of the grade and amount of carbon black modifier.

Title : CARBON BLACK AS A REINFORCING AGENT FOR ASPHALT(AAPT, VOL. 46, 1977)

Authors :F. S. Rostler, R. M. White, and E. M. Dannenberg

The main intention of this paper is to familiarize asphalt technologists with the unique properties of carbon black and its use as a reinforcing agent for asphalt cements.

Fundamental differences between carbon black and conventional asphalt were well discussed. The author emphasized that the development of pelleted carbon black is an essential procedure in order to disperse the carbon black properly in mix design.

Fundamental Properties of Carbon Black

Carbon blacks are manufactured by a partial combustion process using the most advanced engineering principles. More than 40 specification grades of carbon black are manufactured for the rubber , ink, and plastic industries. Many commercially available carbon blacks have mean particle aggregate diameters in the range of 100 to 500 nanometers and surface areas of 15 to over 100 m^2/g. The two basic characteristics by which carbon black is classified are surface area and structure.

(1)Carbon Black structure-measured by the absorption of liquid(DIBUTYL PHTHALATE)
(2) Surface Area - determined by nitrogen or iodine adsorption.

Effect of Carbon Black on Asphalt Properties

The size of carbon black particles and the fact that their surface are hydrophobic, i.e., preferentially wet by hydrocarbon type fluids such as asphalt, makes carbon black, when properly dispersed, a part of the asphalt cement.

Laboratory Tests

The laboratory study presented the development of a pelletized black for use as reinforcing filler for asphalt cement. The pelletized carbon black is necessary to handle loose carbon black in the field and to have proper dispersing effects in the asphalt. The authors stated that loose, fluffy blacks and pelletized blacks for rubber are suitable for the reinforcement for asphalt.

1) The preferred microfiller pellets consist of two components, high structure reinforcing carbon black combined with an asphalt-miscible petroleum oil. The optimum combination will depend on price-performance considerations.

2) The amount of carbon black required to accomplish maximum reinforcing is in the range of 11 - 15 percent by weight of the mixture consisting of asphalt cement, fluxing oil, and carbon black. The 75 : 25 ratio appears to be good compromise for practical applications.

The test results show that:

1) The viscosity increases from the addition of carbon black, and the viscosity decreases from the addition of fluxing oil. It follows from this result that the stiffening effect of the carbon black addition can be counteracted by the use of a particular ratio of fluxing oil to carbon black.

2) The stiffening effect of a filler on asphalt can be judged from the viscosity increase measured with a Brookfield Viscometer at 140 F for a 20 percent concentration using samples prepared in a warring mixer.

Title : Additives have potential to improve pavement life (Road & Bridges, January, 1988)

Authors : Joe W. Button and Dallas N. Little

Asphalt concrete mixtures were tested to determine stability, compatibility and water susceptibility; as well as stiffness , tensile, fatigue and creep/permanent deformation properties as a function of temperature. Three different additives plus carbon black were blended with AC-5 and AR-1000.

Findings from the study clearly show that certain carefully selected and properly applied asphalt additives have the potential to provide cost-effective extensions to pavement service life.

<u>Materials Used</u>

1)Additives
(1) Latex (Emulsified styrene-butadiene-rubber)
(2) Block copolumer rubber (Styrene-butadine-styrene)
(3) Ethylene-vinyl acetate
(4) Finely dispersed polyethene
(5) Carbon black (Microfil 8)

The additives were blended into the mixtures using methods which simulate field conditions as closely as possible.
2)Asphalt Cements
Asphalt for this study are AC-5, AC-10, AC-20 , AR-1000, AR-2000 and AR-4000 grades.

3)Aggregate
The aggregate used in the mixture tests consisted of surrounded, siliceous river gravel and similar sand with limestone crusher fines added to improve stability.

Tests and Results

1) Marshall Method

Marshall method was used to determine optimum binder content with emphasis on uniform air void content(density). Optimum binder content for most of the mixtures was about 4.5 %. Mixtures containing carbon black require a slightly higher binder content (4.75 weight percent).

2) Water Susceptibility Test

The modified, accelerated Lottman moisture treatment procedure was used on mixtures containing both asphalt. It appeared that generally, the additives have little effect on moisture susceptibility of the mixtures.

3) Fatigue Cracking

The potential of asphalt concrete mixtures to crack due to cyclic fatigue was evaluated using a controlled -stress flexural fatigue test. Beams 3 x 3x 15 in. were prepared using the Cox kneading compactor.

Each additive/AC-5 blend produced a mixture which has statistically superior fatigue properties compared to the control mixture using AC-20 asphalt as the binder. The general trend was substantially more flexible response for AC-5 blends containing EVA, SBS(Kraton) and SBR(latex).

4) Deformation Test

Asphalt concrete cylinders 8 in. high and 4 in. in diameter were fabricated using the standard California kneading compactor for the direct compression testing program. Tests on two specimens each at temperatures of 40, 70, and 100°F were performed. The results of creep compliance testing at 40°F and 100°F for mixtures bound with blends of Texas Coastal AC-5 with additives and AC-20 control mixture showed polyethylene in AC-5 exhibited compliance characteristics which were statistically the same as the AC-20 control.

5) Indirect Tension Test

Test results showed that, at the lower temperatures and higher loading rates, the additives increased mixture tensile strength over that of the control mixtures. Strain (deformation) at failure was generally increased by the additives. At the higher temperatures and lower rates, the additives did not appreciably affect the mixture tensile properties.

Conclusions

Each additive proved to be successful to some degree in improving properties on at least one end of the performance spectrum, however, no additives were a cure-all. There is a need, therefore, to develop an additive selection procedure based on conditions of traffic,

pavement structure and climate. The author pointed that a different source of asphalt might show a different behavior when it was blended with additives.

Summary of Field Studies

Title : FIELD EVALUATION OF AN EXPERIMENTAL BITUMINOUS PAVEMENT UTILIZING AN ASPHALT ADDITIVE-CARBON BLACK, FINAL REPORT (Connecticut DOT, 1991)

Author : Eric. C. Lohrey .

The carbon black section and an adjacent control section were surveyed over 5 years. This report shows that results of these tests and compares the performance of the carbon black pavement to that of the control. A general conclusion is that the carbon black was marginally effective in reducing cold weather cracking. Its use to resist hot weather deformation is questionable.

Carbon Black Used

Microfil 8, a special proprietary grade of carbon black, is a pelletized carbonaceous material designed to reinforce and stabilize the asphalt binder in a bituminous concrete mixture.

Description of Test and Pavement Mixture and Costs

The site selected for the experiment is a 1800 ft section of Connecticut Route 3 in the Town of Rocky Hill. The average daily traffic (ADT) for the entire section years prior to and after the installation was as follows: 1979 - 4900 vehicles per day (vpd), 1985 - 7300 vpd; 1987 - 7600 vpd, and 1989 - 8000 vdp. The percentage of trucks has held constant at five thought the period.
The Microfil 8 was added to the mix at a rate of 50-lb per 3-ton batch. This produced a carbon black concentration of approximately 15 percent by weight of the liquid asphalt binder (AC-20).

Cost of carbon black mixture inplace is $54/ton, whereas the cost for conventional class 1 inplace is $36.72/ton. This represents a 47 percent increase in cost for the carbon black pavement overlay. The cost increase could be reduced with a more efficient method of adding the carbon black to the mix at the plant, and a better shipping rate.

Tests and Results

Pavement distress surveys, rutting measurements, deflection measurement, and friction tests were performed in order to compare the carbon black section to the control section.

1) Pavement distress surveys

Visual surveys were performed for three years. Transverse and longitudinal pavement cracking is the only form of distress that has developed at the site to date. It can be concluded that the carbon black contributed to reducing cracking.

2) Rutting Measurements

The tests results were inconclusive. None of the surface profile plots revealed any rutting at all. In addition, no rutting was observed anywhere in either section during the distress surveys. The lack of rutting at the site may be due to the low volume of truck traffic, because rutting , in general, is not a serious problem in Connecticut.

3) Deflection Measurements

The Benkelman beam deflection measurements were performed. The results showed that carbon black section had little effect on the deflection measurements. Generally, the demonstration section had no excessive deflections .

4) Pavement Friction Tests

The tests were performed at, or close to the standard speed of 40 mph. Five year evaluation result show that the overall average of skid number for the carbon black section was recorded as 41.7 and control section was 42.5. From this data, the carbon black had no effect on the pavement skid resistance.

Conclusions

As stated, the rutting and deflection test results showed no difference. However cold-weather cracking of the pavement has slowed.

The increased cost of 47 percent for the carbon black overlay is quite high. In order to the use of carbon black be economical, the life of pavement would have be substantially increased. At this time, certain pavement section, prone to cracking where a heavily traveled intersection tend to premature pavement failure, may have their service lives extended by use of carbon black, but widespread use of the carbon black would not be economical.

Title : EVALUATION OF CARBON BLACK EXPERIMENTAL CONSTRUCTION 84-02 (MAINE DOT, 1990)

Author : Warren T. Foster

This report discusses the relative performance of a bituminous pavement, containing the additive carbon black, after 70 months of service.

Descriptions of pavement sites

Carbon black was incorporated into the bituminous pavement on a section of project 282-0(008) on Route 178 in Milford, Maine in September 1984. The average daily traffic for this section of Route 178 is approximately 2500 vehicles with a significant number of heavily loaded forest product trucks.

Mix Design

The asphalt pavement having the additive carbon black was used for a 1-1/4 in. wearing surface that was placed on 1-3/4 in. of binder "Grading B". The grading B was MDOT's standard mix and did not contain carbon black. An AC-10 asphalt was used in all the mixes.

Evaluation

This project was visually evaluated annually. The pavement began to exhibit signs of deterioration with time. The study section of Route 178 has definitely deteriorated over the 70 month evaluation period and currently is considered in fair condition. However, the relative performance between section with carbon black pavement and without carbon black shows no differences. Therefore, the addition of carbon black did not result in superior pavement performance in this particular application.

APPENDIX B

Bulk Specific Gravity of Marshall Specimens

BULK SPECIFIC GRAVITY
OF
BITUMINOUS MIXTURES USING
SATURATED SURFACE-DRY SPECIMENS
(ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC10 (20% PCB) Compaction Method 75 blows per side
Date Tested : 6/7/94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1232.1	1232.1	1231.9	1244.8	1237.0
B.SSD Wt. (g)	1255.5	1252.5	1256.3	1259.4	1255.3
C.Wt. in Water (g)	729.3	731.8	731.0	734.5	731.7
D.Volume (cm³) B -C	526.2	520.7	525.3	524.9	523.6
E.Bulk S.G A/D	2.342	2.366	2.345	2.371	2.362

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1244.7	1242.8	1242.1	1242.1	1252.0
B.SSD Wt. (g)	1260.4	1253.9	1252.3	1253.8	1259.2
C.Wt. in Water (g)	733.9	730.4	732.0	732.8	736.5
D.Volume (cm³) B -C	526.5	523.5	520.3	521.0	522.7
E.Bulk S.G A/D	2.364	2.374	2.387	2.384	2.391

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1247.8	1251.0	1257.5	1254.2	1256.5
B.SSD Wt. (g)	1255.9	1259.1	1262.2	1259.8	1260.5
C.Wt. in Water (g)	733.5	739.0	737.2	737.8	743.5
D.Volume (cm³) B -C	522.4	520.1	525.0	522.0	517.0
E.Bulk S.G A/D	2.389	2.405	2.395	2.403	2.430

BULK SPECIFIC GRAVITY
OF
BITUMINOUS MIXTURES USING
SATURATED SURFACE-DRY SPECIMENS
(ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC-20 Compaction Method 75 blows per side
Date Tested : 3/17/94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1222.7	1228.2	1232.8	1228.8	1239.9
B.SSD Wt. (g)	1236.3	1240.8	1246.7	1234.8	1245.3
C.Wt. in Water (g)	723.5	723.8	728.1	724.9	730.7
D.Volume (cm^3) B -C	512.8	517.0	518.6	509.9	514.6
E.Bulk S.G A/D	2.384	2.376	2.377	2.41	2.41

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1238.4	1237.6	1234.7	1239.5	1243.2
B.SSD Wt. (g)	1244.9	1241.7	1238.6	1242.7	1247.0
C.Wt. in Water (g)	728.8	731.4	726.7	732.0	736.4
D.Volume (cm^3) B -C	516.1	510.3	511.9	510.7	510.6
E.Bulk S.G A/D	2.4	2.425	2.412	2.427	2.435

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1239.1	1239.9	1246.3	1251.0	1252.3
B.SSD Wt. (g)	1242.8	1243.4	1249.3	1254.2	1254.7
C.Wt. in Water (g)	734.2	731.9	739.1	741.3	739.9
D.Volume (cm^3) B -C	508.6	511.5	510.2	512.9	514.8
E.Bulk S.G A/D	2.436	2.424	2.443	2.439	2.433

BULK SPECIFIC GRAVITY
OF
BITUMINOUS MIXTURES USING
SATURATED SURFACE-DRY SPECIMENS
(ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC 20 (10% CB)   Compaction Method 75 blows per side
Date Tested : 5/16/94   Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1227.8	1237.6	1232.2	1237.4	1235.9
B.SSD Wt. (g)	1242.7	1253.5	1250.3	1248.5	1248.9
C.Wt. in Water (g)	724.8	732.7	729.5	730.2	729.1
D.Volume (cm^3) B -C	517.9	520.8	520.8	518.3	519.8
E.Bulk S.G A/D	2.371	2.376	2.366	2.387	2.378

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1240.4	1241.0	1244.5	1237.0	1240.7
B.SSD Wt. (g)	1251.2	1245.6	1249.5	1243.0	1244.8
C.Wt. in Water (g)	731.6	737.2	736.4	727.2	733.6
D.Volume (cm^3) B -C	519.6	508.4	513.1	515.8	511.2
E.Bulk S.G A/D	2.387	2.441	2.425	2.398	2.427

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1250.5	1247.3	1250.8	1250.8	1249.6
B.SSD Wt. (g)	1254.4	1250.8	1253.5	1253.7	1252.9
C.Wt. in Water (g)	740.6	732.4	739.8	741.1	741.7
D.Volume (cm^3) B -C	513.8	518.4	513.7	512.6	511.2
E.Bulk S.G A/D	2.434	2.406	2.435	2.440	2.444

BULK SPECIFIC GRAVITY
OF
BITUMINOUS MIXTURES USING
SATURATED SURFACE-DRY SPECIMENS
(ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC20 (15% CB) Compaction Method 75 blows per side
Date Tested : 5/24 /94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1233.8	1233.3	1228.5	1239.6	1236.6
B.SSD Wt. (g)	1253.7	1253.6	1247.6	1249.8	1247.6
C.Wt. in Water (g)	732.2	732.3	729.8	733.9	733.2
D.Volume (cm^3) B -C	521.5	521.3	517.8	515.9	514.4
E.Bulk S.G A/D	2.366	2.366	2.373	2.403	2.404

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1242.1	1236.9	1235.6	1236.9	1248.4
B.SSD Wt. (g)	1253.2	1242.8	1241.5	1241.1	1255.1
C.Wt. in Water (g)	734.3	730.8	730.2	724.3	741.5
D.Volume (cm^3) B -C	518.9	512.0	511.3	516.8	513.6
E.Bulk S.G A/D	2.394	2.416	2.417	2.393	2.431

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1244.9	1244.1	1258.3	1256.2	1252.7
B.SSD Wt. (g)	1255.5	1248.7	1261.4	1259.5	1256.6
C.Wt. in Water (g)	738.2	737.9	744.2	742.1	743.8
D.Volume (cm^3) B -C	517.3	510.8	517.2	517.4	512.8
E.Bulk S.G A/D	2.407	2.436	2.433	2.428	2.443

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES USING SATURATED SURFACE-DRY SPECIMENS (ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC20 (20% CB) Compaction Method 75 blows per side
Date Tested : 5/19/94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1230.3	1227.8	1234.0	1241.2	1239.3
B.SSD Wt. (g)	1250.8	1251.1	1256.5	1256.6	1256.6
C.Wt. in Water (g)	731.2	731.0	729.9	733.1	734.9
D.Volume (cm^3) B -C	519.6	521.2	526.6	523.5	521.7
E.Bulk S.G A/D	2.368	2.361	2.343	2.371	2.376

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1240.2	1242.4	1237.1	1248.4	1248.3
B.SSD Wt. (g)	1255.2	1251.4	1246.4	1255.7	1253.3
C.Wt. in Water (g)	735.0	733.2	727.6	738.8	737.9
D.Volume (cm^3) B -C	520.2	518.2	518.8	516.9	515.4
E.Bulk S.G A/D	2.384	2.398	2.385	2.415	2.422

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1250.3	1243.6	1247.4	1251.6	1248.2
B.SSD Wt. (g)	1256.7	1248.0	1253.2	1255.0	1252.9
C.Wt. in Water (g)	732.3	739.5	736.4	738.4	738.7
D.Volume (cm^3) B -C	524.4	508.5	516.8	516.6	514.2
E.Bulk S.G A/D	2.384	2.446	2.414	2.423	2.427

BULK SPECIFIC GRAVITY
OF
BITUMINOUS MIXTURES USING
SATURATED SURFACE-DRY SPECIMENS
(ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC20 (5%PCB)   Compaction Method 75 blows per side
Date Tested : 4/20/94   Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1227.8	1233.4	1228.3	1241.5	1239.2
B.SSD Wt. (g)	1243.9	1247.8	1244.2	1248.6	1249.2
C.Wt. in Water (g)	725.0	731.2	726.7	731.4	732.5
D.Volume (cm^3) B -C	518.9	516.6	517.5	517.2	516.7
E.Bulk S.G A/D	2.366	2.387	2.373	2.400	2.398

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1236.2	1240.9	1222.4	1241.2	1248.8
B.SSD Wt. (g)	1244.3	1245.1	1226.3	1245.9	1245.4
C.Wt. in Water (g)	730.4	729.2	717.5	732.6	737.3
D.Volume (cm^3) B -C	513.9	515.9	508.8	513.3	511.5
E.Bulk S.G A/D.	2.400	2.405	2.403	2.418	2.435

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1247.7	1248.2	1250.0	1248.3	1251.0
B.SSD Wt. (g)	1243.9	1244.4	1253.1	1251.4	1253.7
C.Wt. in Water (g)	734.8	735.2	741.6	740.0	740.0
D.Volume (cm^3) B -C	512.9	513.0	511.5	511.4	513.7
E.Bulk S.G A/D	2.425	2.426	2.444	2.440	2.435

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES USING SATURATED SURFACE-DRY SPECIMENS (ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC20 (10% PCB) Compaction Method 75 blows per side
Date Tested : 4/25/94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1230.5	1232.2	1234.2	1237.7	1235.8
B.SSD Wt. (g)	1250.5	1251.3	1251.1	1250.0	1248.1
C.Wt. in Water (g)	728.7	730.3	729.9	730.0	727.8
D.Volume (cm³) B -C	521.8	521.0	521.2	520.0	520.3
E.Bulk S.G A/D	2.358	2.365	2.367	2.380	2.375

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1243.4	1241.0	1244.4	1247.3	1250.7
B.SSD Wt. (g)	1256.1	1247.8	1251.6	1254.1	1256.1
C.Wt. in Water (g)	732.8	728.4	732.8	734.8	736.4
D.Volume (cm³) B -C	523.8	519.4	518.8	519.3	519.7
E.Bulk S.G A/D	2.376	2.389	2.399	2.402	2.407

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1251.1	1248.5	1258.8	1249.7	1252.4
B.SSD Wt. (g)	1255.8	1253.8	1262.2	1253.8	1255.6
C.Wt. in Water (g)	738.3	734.4	741.4	739.8	740.5
D.Volume (cm³) B -C	517.5	519.4	520.8	514.0	515.1
E.Bulk S.G A/D	2.418	2.404	2.417	2.431	2.431

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES USING SATURATED SURFACE-DRY SPECIMENS (ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC20 (15% PCB) Compaction Method 75 blows per side
Date Tested : 4/26/94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1229.8	1232.7	1237.9	1237.2	1239.6
B.SSD Wt. (g)	1249.8	1252.5	1257.8	1254.7	1254.8
C.Wt. in Water (g)	730.3	732.5	733.8	729.1	731.6
D.Volume (cm^3) B -C	519.5	520.0	524.0	525.6	523.2
E.Bulk S.G A/D	2.367	2.37	2.362	2.354	2.369

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1244.5	1244.1	1243.5	1244.6	1250.2
B.SSD Wt. (g)	1256.2	1254.4	1254.4	1252.6	1256.3
C.Wt. in Water (g)	734.1	731.8	732.3	731.5	733.7
D.Volume (cm^3) B -C	522.1	522.6	522.1	521.1	522.6
E.Bulk S.G A/D	2.384	2.381	2.382	2.388	2.392

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1249.4	1252.7	1251.0	1254.5	1254.1
B.SSD Wt. (g)	1256.0	1257.7	1254.8	1259.3	1258.7
C.Wt. in Water (g)	732.2	738.0	737.2	738.6	737.5
D.Volume (cm^3) B -C	523.8	519.7	517.6	520.7	521.2
E.Bulk S.G A/D	2.385	2.410	2.417	2.409	2.406

BULK SPECIFIC GRAVITY OF BITUMINOUS MIXTURES USING SATURATED SURFACE-DRY SPECIMENS (ASTM D2726)

Laboratory : INDOT Division of Research Material Lab.
Mixture Type : : AC 20 (20% PCB) Compaction Method 75 blows per side
Date Tested : 5/6 /94 Tested by : TAESOON PARK

Sample I.D.	3.5 - 1	3.5 - 2	3.5 -3	4 - 1	4 - 2
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A. Dry Wt. in Air (g)	1233.0	1238.9	1235.7	1249.3	1242.3
B.SSD Wt. (g)	1257.4	1260.5	1257.4	1262.1	1261.6
C.Wt. in Water (g)	730.8	731.9	730.2	736.7	733.7
D.Volume (cm^3) B -C	528.6	528.6	527.2	525.4	527.9
E.Bulk S.G A/D	2.333	2.344	2.344	2.378	2.353

Sample I.D.	4 - 3	4.5 - 1	4.5 - 2	4.5 - 3	5 - 1
Diameter (in.)	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1245.2	1245.3	1246.1	1252.2	1251.4
B.SSD Wt. (g)	1260.9	1255.6	1257.4	1265.1	1258.3
C.Wt. in Water (g)	735.9	732.9	735.1	738.9	734.6
D.Volume (cm^3) B -C	525.0	514.6	522.3	526.2	523.7
E.Bulk S.G A/D	2.372	2.382	2.386	2.380	2.390

Sample I.D.	5 - 2	5 - 3	5.5 - 1	5.5 - 2	5.5 - 3
Diameter	4	4	4	4	4
Thickness (in.)					
A.Dry Wt. in Air (g)	1255.0	1251.1	1259.6	1256.0	1255.7
B.SSD Wt. (g)	1262.3	1257.1	1264.8	1261.6	1259.9
C.Wt. in Water (g)	738.2	736.0	741.1	742.7	738.7
D.Volume (cm^3) B -C	524.1	521.1	523.7	518.9	521.2
E.Bulk S.G A/D	2.395	2.40	2.405	2.421	2.409

APPENDIX C

Maximum Theoretical Specific Gravity of Marshall Specimens

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1220.7	1221.6	1229.4
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8711.7	8712.6	8720.4
4.Wt. of Sample after Evaluation	8248.3	8248.8	8720.4
5.(#3 - #4)	463.4	463.8	467.9
6.#1/#5 =S.G	2.634	2.633	2.627

Standard Deviation =
Range = Average = 2.631x 62.43 = 164.25 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1233.6	1231.4	1230.3
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8724.6	8722.4	8721.3
4.Wt. of Sample after Evaluation	8250.8	8249.5	8247.2
5.(#3 - #4)	473.8	472.9	474.1
6.#1/#5 =S.G	2.604	2.604	2.595

Standard Deviation =
Range = Average = 2.601x 62.43 = 162.38 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	4.5 -1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1244.1	1245.2	1238.9
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.1	8736.2	8729.9
4.Wt. of Sample after Evaluation	8252.6	8255.9	8251.4
5.(#3 - #4)	478.5	480.3	477.8
6.#1/#5 =S.G	2.594	2.593	2.593

Standard Deviation =
Range = Average = 2.593x 62.43 = 161.88 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1240.1	1240.1	1236.6
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.1	8249.0	8727.6
4.Wt. of Sample after Evaluation	8247.6	8249.0	8247.3.8
5.(#3 - #4)	483.5	482.1	480.3
6.#1/#5 =S.G	2.565	2.572	2.575

Standard Deviation =
Range = Average = 2.571x 62.43 = 160.51 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 -1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1244.1	1245.2	1238.9
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.1	8736.2	8729.9
4.Wt. of Sample after Evaluation	8252.6	8255.9	8251.4
5.(#3 - #4)	478.5	480.3	477.8
6.#1/#5 =S.G	2.594	2.593	2.593

Standard Deviation =
Range = Average = 2.593x 62.43 = 161.88 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1240.1	1240.1	1236.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.1	8249.0	8727.6
4.Wt. of Sample after Evaluation	8247.6	8249.0	8247.3.8
5.(#3 - #4)	483.5	482.1	480.3
6.#1/#5 =S.G	2.565	2.572	2.575

Standard Deviation =
Range = Average = 2.571x 62.43 = 160.51 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 **Run Date :** Jun.1, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1233.1	1252.1	1253.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8724.1	8743.1	8744.1
4.Wt. of Sample after Evaluation	8240.1	8251.7	8252.4
5.(#3 - #4)	484.0	491.4	491.7
6.#1/#5 =S.G	2.548	2.548	2.549

Standard Deviation =
Range = Average = 2.548x 62.43 = 159.07 bs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% CB) **Run Date :** Jun. 15, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample	1225.8	1223.4	1217.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8716.8	8714.4	8708.7
4.Wt. of Sample after Evaluation	8252.5	8251.4	8247.8
5.(#3 - #4)	464.3	463	460.9
6.#1/#5 =S.G	2.64	2.642	2.642

Standard Deviation =
Range = Average = 2.641x 62.43 = 164.88 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% CB) **Run Date :** Jun, 15, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample	1240.5	1232.2	1235.4
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.5	8723.2	8726.4
4.Wt. of Sample after Evaluation	8257.5	8252.8	8253.6
5.(#3 - #4)	474.0	470.4	472.8
6.#1/#5 =S.G	2.617	2.619	2.613

Standard Deviation =
Range = Average = 2.616x 62.43 = 163.33 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% CB) **Run Date :** Jun. 15, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample	1237.2	1228.3	1232.9
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8728.2	8719.3	8723.9
4.Wt. of Sample after Evaluation	8252.2	8247.3	8253.8
5.(#3 - #4)	476.0	472.0	470.1
6.#1/#5 =S.G	2.599	2.602	2.623

Standard Deviation =
Range = Average = 2.608x 62.43 = 162.82 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% CB) **Run Date :** Jun. 15, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 -3
1.Wt. of Sample	1243.2	1239.2	1240.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8734.2	8730.2	8731.6
4.Wt. of Sample after Evaluation	8252.7	8250.4	8251.3
5.(#3 - #4)	481.5	479.8	480.3
6.#1/#5 =S.G	2.582	2.583	2.583

Standard Deviation =
Range = Average = 2.583x 62.43 = 161.26 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10(5% CB) **Run Date :** Jun. 15, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample	1240.5	1248.0	1243.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.5	8739.0	8734.5
4.Wt. of Sample after Evaluation	8248.4	8252.0	8250.1
5.(#3 - #4)	483.1	487.0	484.4
6.#1/#5 =S.G	2.568	2.563	2.567

Standard Deviation =
Range = Average = 2.566x 62.43 = 160.2 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : **Run Date :**
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10 % CB) **Run Date :**Jun. 16,1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 -1	3.5 -2	3.5 - 3
Wt. of Sample(g)	1237.3	1233.0	1233.4
Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
Wt. of #1+#2	8728.3	8724.0	8724.4
Wt. of Sample after Evaluation	8206.1	8257.3	8258.1
(#3 - #4)	468.2	466.7	466.3
#1/#5 =S.G	2.643	2.642	2.645

Standard Deviation =
Range = Average = 2.643x 62.43 = 165 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% CB) **Run Date :** Jun. 16,1994
Tested by :TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
Wt. of Sample(g)	1238.9	1233.8	1238.9
Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
Wt. of #1+#2	8729.9	8724.8	8729.9
Wt. of Sample after Evaluation	8258.4	8255.3	8257.4
(#3 - #4)	471.5	469.5	472.5
#1/#5 =S.G	2.624	2.628	2.622

Standard Deviation =
Range = Average = 2.625x 62.43 = 163.88 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% CB) **Run Date :** Jun. 16, 1994
Tested by :TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	4.5 - 1	4.5 -2	4.5 - 3
Wt. of Sample	1229.1	1230	1244.1
Wt.of Pyc + Water	7491.0	7491.0	7491.0
Wt. of #1+#2	8720.1	8721.0	8735.1
Wt. of Sample after Evaluation	8249.1	8721.0	8735.1
(#3 - #4)	470.7	471.5	477.8
#1/#5 =S.G	2.611	2.609	2.604

Standard Deviation =
Range = Average = 2.608x 62.43 = 162.82 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% CB) **Run Date :** Jun 16, 1994
Tested by :TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	5 - 1	5 - 2	5 - 3
Wt. of Sample	1242.0	1244.1	1240.3
Wt.of Pyc + Water	7491.0	7491.0	7491.0
Wt. of #1+#2	8733.0	8735.1	8731.3
Wt. of Sample after Evaluation	8253.3	8254.3	8252.0
(#3 - #4)	479.7	480.8	479.3
#1/#5 =S.G	2.589	2.588	2.588

Standard Deviation =
Range = Average = 2.588x 62.43 = 161.57 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% CB) **Run Date :** Jun. 16, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample	1239.7	1247.2	1249.3
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8730.7	8738.2	8740.3
4.Wt. of Sample after Evaluation	8248.5	8252.5	8253.7
5.(#3 - #4)	482.2	485.7	486.6
6.#1/#5 =S.G	2.571	2.568	2.567

Standard Deviation =
Range = Average = 2.569x 62.43 = 160.38 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : **Run Date :**
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% CB) **Run Date :** Jun. 19, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 -3
1.Wt. of Sample (g)	1237.9	1232.9	1232.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8728.9	8723.9	8723.7
4.Wt. of Sample after Evaluation	8260.5	8258.6	8257.4
5.(#3 - #4)	468.4	465.3	466.3
6.#1/#5 =S.G	2.643	2.65	2.644

Standard Deviation =
Range = Average = 2.646x 62.43 = 165.19 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% CB) **Run Date :** Jun. 19, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1241.6	1238.4	1235.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.6	8729.4	8726.7
4.Wt. of Sample after Evaluation	8260.1	8258.7	8257.1
5.(#3 - #4)	472.5	470.7	469.6
6.#1/#5 =S.G	2.628	2.631	2.631

Standard Deviation =
Range = Average = 2.63x 62.43 = 164.2 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% CB) **Run Date :** Jun.19, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1233.4	1234.7	1245.3
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8724.4	8725.7	8736.3
4.Wt. of Sample after Evaluation	8252.2	8253.8	8258.5
5.(#3 - #4)	472.2	471.9	477.8
6.#1/#5 =S.G	2.612	2.616	2.606

Standard Deviation =
Range = Average = 2.611x 62.43 = 163.0 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% CB) **Run Date :** Jun. 19, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1247.2	1245.5	1244.3
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8738.2	8736.5	8735.3
4.Wt. of Sample after Evaluation	8257.4	8256.2	8255.3
5.(#3 - #4)	480.8	480.3	480.0
6.#1/#5 =S.G	2.594	2.593	2.592

Standard Deviation =
Range = Average = 2.593x 62.43 = 161.88 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% CB) **Run Date :** Jun.19, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 2
1.Wt. of Sample (g)	1252.5	1248.5	1253.9
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8743.5	8739.5	8744.9
4.Wt. of Sample after Evaluation	8256.9	8255.3	8257.0
5.(#3 - #4)	486.6	484.2	487.9
6.#1/#5 =S.G	2.574	2.578	2.57

Standard Deviation =
Range = Average = 2.574x 62.43 = 160.69 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% CB) **Run Date :** Jun.21, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	N/A	1226.3	1221.8
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	N/A	8717.3	8712.8
4.Wt. of Sample after Evaluation		8255.5	8252.6
5.(#3 - #4)	.	461.8	460.2
6.#1/#5 =S.G		2.655	2.655

Standard Deviation =
Range = Average = 2.655x 62.43 = 165.75 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% CB) **Run Date :** Jun.21, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1242.8	1241.6	1234.9
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8733.8	8732.6	8725.9
4.Wt. of Sample after Evaluation	8261.2	8260.2	8255.7
5.(#3 - #4)	472.6	472.4	470.2
6.#1/#5 =S.G	2.630	2.628	2.626

Standard Deviation =
Range = Average = 2.628x 62.43 = 164.07 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% CB) **Run Date :** Jun.21, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1241.2	1244.6	1243.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.2	8735.6	8734.6
4.Wt. of Sample after Evaluation	8257.2	8258.7	8258.4
5.(#3 - #4)	475.0	476.9	476.2
6.#1/#5 =S.G	2.613	2.610	2.612

Standard Deviation =
Range = Average = 2.612x 62.43 = 163.07 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% CB) **Run Date :** Jun.21, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1254.0	1250.2	1248.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8745.0	8741.8	8739.7
4.Wt. of Sample after Evaluation	8260.4	8259.4	8257.5
5.(#3 - #4)	484.1	482.4	482.2
6.#1/#5 =S.G	2.590	2.593	2.590

Standard Deviation =
Range = Average = 2.591x 62.43 = 161.76 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% CB) **Run Date :** Jun.21, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1251.0	1247.3	1251.4
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8742.0	8738.3	8742.4
4.Wt. of Sample after Evaluation	8256.5	8253.6	8256.6
5.(#3 - #4)	485.5	484.7	485.8
6.#1/#5 =S.G	2.577	2.573	2.576

Standard Deviation =
Range = Average = 2.575x 62.43 = 160.76 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% PCB) **Run Date :** Jun.3, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1223.9	1229.5	1233.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8714.9	8720.5	8724.8
4.Wt. of Sample after Evaluation	8251.6	8254.0	8255.7
5.(#3 - #4)	463.3	466.5	469.1
6.#1/#5 =S.G	2.642	2.636	2.630

Standard Deviation =
Range = Average = 2.636x 62.43 = 164.57 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% PCB) **Run Date :** Jun.3, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1241.2	1234.2	1239.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.2	8725.2	8730.7
4.Wt. of Sample after Evaluation	8258.7	8253.7	8256....6
5.(#3 - #4)	473.5	471.8	474.1
6.#1/#5 =S.G	2.621	2.616	2.615

Standard Deviation =
Range = Average = 2.617x 62.43 = 163.38 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% PCB) **Run Date :** Jun.3, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1241.4	1234.6	1243.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.4	8725.6	8734.2
4.Wt. of Sample after Evaluation	8252.3	8249.4	8253.1
5.(#3 - #4)	480.1	476.2	481.1
6.#1/#5 =S.G	2.586	2.593	2.584

Standard Deviation =
Range = Average = 2.588x 62.43 = 161.57 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% PCB) **Run Date :** Jun.3, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1241.4	1242.0	1247.5
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.4	8733.0	8738.5
4.Wt. of Sample after Evaluation	8248.4	8251.7	8252.2
5.(#3 - #4)	484.0	481.3	486.3
6.#1/#5 =S.G	2.565	2.580	2.565

Standard Deviation =
Range = Average = 2.570x 62.43 = 160.45 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (5% PCB) **Run Date :** Jun.3, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1249.7	1250.3	1246.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8740.7	8741.3	8737.6
4.Wt. of Sample after Evaluation	8251.0	8252.0	8249.4
5.(#3 - #4)	489.7	489.3	488.2
6.#1/#5 =S.G	2.552	2.555	2.553

Standard Deviation =
Range = Average = 2.553x 62.43 = 159.38 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% PCB) **Run Date :** Jun.8, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1229.9	1230.0	1229.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8720.9	8721.0	8720.1
4.Wt. of Sample after Evaluation	8256.0	8256.6	8255.3
5.(#3 - #4)	464.9	464.4	464.8
6.#1/#5 =S.G	2.646	2.649	2.644

Standard Deviation =
Range = Average = 2.646x 62.43 = 165.19 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% PCB) **Run Date :** Jun.8, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1235.0	1238.1	1236.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8726.0	8729.1	8727.5
4.Wt. of Sample after Evaluation	8255.0	8255.6	8255.3
5.(#3 - #4)	471	473.5	472.2
6.#1/#5 =S.G	2.622	2.615	2.619

Standard Deviation =
Range = Average = 2.619x 62.43 = 163.5 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% PCB) **Run Date :** Jun.8, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1241.9	1245.5	1242.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.9	8736.5	8733.7
4.Wt. of Sample after Evaluation	8255.2	8256.5	8254.4
5.(#3 - #4)	477.2	480.0	479.3
6.#1/#5 =S.G	2.602	2.595	2.593

Standard Deviation =
Range = Average = 2.597x 62.43 = 162.13 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% PCB) **Run Date :** Jun.8, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1249.4	1247.0	1240.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8740.4	8738.0	8731.5
4.Wt. of Sample after Evaluation	8256.7	8254.2	8250.6
5.(#3 - #4)	483.7	483.8	480.9
6.#1/#5 =S.G	2.583	2.578	2.579

Standard Deviation =
Range = Average = 2.58x 62.43 = 161.07 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (10% PCB) **Run Date :** Jun.8, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1250.7	1246.9	1244.7
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8741.7	8737.9	8735.7
4.Wt. of Sample after Evaluation	8254.7	8252.9	8249.0
5.(#3 - #4)	487.0	485.0	486.7
6.#1/#5 =S.G	2.568	2.571	2.557

Standard Deviation =
Range = Average = 2.565x 62.43 = 160.13 bs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% PCB) **Run Date :** Jun.10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1228.6	1229.2	1233.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8719.6	8720.2	8724.1
4.Wt. of Sample after Evaluation	8256.3	8254.7	8258.0
5.(#3 - #4)	463.3	465.5	466.1
6.#1/#5 =S.G	2.652	2.641	2.646

Standard Deviation =
Range = Average = 2.646x 62.43 = 165.19 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% PCB) **Run Date :** Jun.10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1239.3	1239.2	1236.0
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8730.3	8730.2	8727.0
4.Wt. of Sample after Evaluation	8257.7	8257.4	8255.5
5.(#3 - #4)	472.6	472.8	471.5
6.#1/#5 =S.G	2.622	2.621	2.621

Standard Deviation =
Range = Average = 2.621x 62.43 = 163.63 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% PCB) **Run Date :** Jun.10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1245.5	1240.6	1242.6
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8736.5	8731.6	8733.6
4.Wt. of Sample after Evaluation	8260.0	8255.1	8256.2
5.(#3 - #4)	476.5	476.5	477.4
6.#1/#5 =S.G	2.612	2.604	2.603

Standard Deviation =
Range = Average = 2.606x 62.43 = 162.51 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% PCB) **Run Date :** Jun.10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1248.7	1247.9	1250.1
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8739.7	8738.9	8741.1
4.Wt. of Sample after Evaluation	8256.7	8256.0	8257.8
5.(#3 - #4)	483	482.9	483.3
6.#1/#5 =S.G	2.585	2.584	2.587

Standard Deviation =
Range = Average = 2.585x 62.43 = 161.38 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (15% PCB) **Run Date :** Jun.10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1254.5	1253.1	1251.0
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8745.5	8744.1	8742.0
4.Wt. of Sample after Evaluation	8257.6	8257.1	8253.2
5.(#3 - #4)	487.9	487	488.8
6.#1/#5 =S.G	2.571	2.573	2.559

Standard Deviation =
Range = Average = 2.568x 62.43 = 160.32 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% PCB) **Run Date :** Jun.13, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1226.4	1230.4	1230.6
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8717.4	8721.4	8721.6
4.Wt. of Sample after Evaluation	8255.1	8257.6	8258.0
5.(#3 - #4)	462.3	463.8	463.6
6.#1/#5 =S.G	2.653	2.653	2.654

Standard Deviation =
Range = Average = 2.653x 62.43 = 165.63 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% PCB) **Run Date :** Jun.13, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1243.6	1236.6	1245.3
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8734.6	8727.6	8736.3
4.Wt. of Sample after Evaluation	8261.5	8257.6	8263.2
5.(#3 - #4)	473.1	470.0	473.1
6.#1/#5 =S.G	2.629	2.631	2.632

Standard Deviation =
Range = Average = 2.631x 62.43 = 164.25 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% PCB) **Run Date :** Jun.13, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1241.2	1241.2	1242.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.2	8732.2	8733.2
4.Wt. of Sample after Evaluation	8257.8	8257.2	8258.5
5.(#3 - #4)	474.4	475	474.7
6.#1/#5 =S.G	2.616	2.613	2.617

Standard Deviation =
Range = Average = 2.615x 62.43 = 163.25 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% PCB) **Run Date :** Jun.13, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1252.7	1245.4	1249.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8743.7	8736.4	8740.5
4.Wt. of Sample after Evaluation	8261.4	8256.4	8260.2
5.(#3 - #4)	482.3	480	480.3
6.#1/#5 =S.G	2.597	2.595	2.601

Standard Deviation =
Range = Average = 2.598x 62.43 = 162.19 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-10 (20% PCB) **Run Date :** Jun.13, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1257.7.	1253.1	1255.3
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8748.7	8744.1	8746.3
4.Wt. of Sample after Evaluation	8261.4	8258.7	8259.5
5.(#3 - #4)	487.3	485.4	486.8
6.#1/#5 =S.G	2.581	2.582	2.577

Standard Deviation =
Range = Average = 2.580x 62.43 = 161.07 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Mar. 17, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1223.3	1227.3	1229.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8714.3	8718.3	8720.5
4.Wt. of Sample after Evaluation	8250	8248	8246
5.(#3 - #4)	464.3	470.3	474.5
6.#1/#5 =S.G	2.635	2.610	2.591

Standard Deviation =
Range = Average = 2.612x 62.43 = 163.07 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Mar. 17, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1226.7	1236.1	1235.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8717.7	8727.1	8726.8
4.Wt. of Sample after Evaluation	8239.1	8250.1	8250.0
5.(#3 - #4)	478.6	477	476.8
6.#1/#5 =S.G	2.563	2.594	2.592

Standard Deviation =
Range = Average = 2.583x 62.43 = 161.26 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Mar. 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1232.0	1231.2	1236.0
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8723.0	8722.3	8727
4.Wt. of Sample after Evaluation	8241.7	8236.4	8238
5.(#3 - #4)	481.3	485.9	489.0
6.#1/#5 =S.G	2.559	2.534	2.528

Standard Deviation =
Range = Average = 2.540x 62.43 = 158.57 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Mar. 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1240.9	1236	1237.3
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.9	8727	8728.3
4.Wt. of Sample after Evaluation	8234	8231.5	8239
5.(#3 - #4)	497.9	495.5	489.3
6.#1/#5 =S.G	2.492	2.494	2.529

Standard Deviation =
Range = Average = 2.493x 62.43 = 155.64 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Mar. 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1236.5	1242.9	N/A
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8727.5	8733.9	
4.Wt. of Sample after Evaluation	8225.4	8733.9	
5.(#3 - #4)	502.1	502.8	
6.#1/#5 =S.G	2.462	2.471	

Standard Deviation =
Range = Average = 2.467x 62.43 = 154.01 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% CB) **Run Date :** May 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1226.8	1237.0	1231.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8717.8	8728.0	8722.1
4.Wt. of Sample after Evaluation	8250.7	8256.6	8254.0
5.(#3 - #4)	467.1	471.4	468.1
6.#1/#5 =S.G	2.626	2.624	2.630

Standard Deviation =
Range = Average = 2.627x 62.43 = 164 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% CB) **Run Date :** May 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1235.5	1233.6	1237.3
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8726.5	8724.6	8728.3
4.Wt. of Sample after Evaluation	8247.8	8253.6	8254.4
5.(#3 - #4)	478.7	471	473.9
6.#1/#5 =S.G	2.581	2.619	2.610

Standard Deviation =
Range = Average = 2.618x 62.43 = 163.44 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% CB) **Run Date :** May 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1239.5	1241.4	1234.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8730.5	8732.4	8725.6
4.Wt. of Sample after Evaluation	8250.5	8253.0	8248.3
5.(#3 - #4)	480	479.4	477.3
6.#1/#5 =S.G	2.582	2.589	2.587

Standard Deviation =
Range = Average = 2.586x 62.43 = 161.44 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% CB) **Run Date :** May 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1237.5	1249.5	1246.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8728.5	8740.5	8737.8
4.Wt. of Sample after Evaluation	8247.0	8254.5	8253.0
5.(#3 - #4)	481.5	486.0	484.8
6.#1/#5 =S.G	2.570	2.571	2.572

Standard Deviation =
Range = Average = 2.571x 62.43 = 160.51 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% CB) **Run Date :** May 18, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1250.6	1249.2	1247.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8741.6	8740.2	8738.2
4.Wt. of Sample after Evaluation	8252.2	8252.0	8250.7
5.(#3 - #4)	489.4	488.2	489.5
6.#1/#5 =S.G	2.555	2.559	2.558

Standard Deviation =
Range = Average = 2.557x 62.43 = 159.63 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% CB) **Run Date :** May 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1230.2	1232.3	1226.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8721.2	8723.3	8717.8
4.Wt. of Sample after Evaluation	8256.4	8257.1	8252.4
5.(#3 - #4)	465.0	466.2	465.4
6.#1/#5 =S.G	2.646	2.643	2.636

Standard Deviation =
Range = Average = 2.642x 62.43 = 164.94 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% CB) **Run Date :** May 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1238.7	1235.6	1240.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8729.7	8726.6	8731.6
4.Wt. of Sample after Evaluation	8259.8	8257.8	8258.4
5.(#3 - #4)	469.9	468.8	473.2
6.#1/#5 =S.G	2.636	2.635	2.622

Standard Deviation =
Range = Average = 2.631x 62.43 = 164.25 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% CB) **Run Date :** Jun. 6, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1236.1	1234.6	1236.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8727.1	8725.6	8727.1
4.Wt. of Sample after Evaluation	8253.2	8252.6	8252.3
5.(#3 - #4)	473.9	473.0	474.8
6.#1/#5 =S.G	2.608	2.610	2.603

Standard Deviation =
Range = Average = 2.607x 62.43 = 162.76 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% CB) **Run Date :** May 26, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1247.8	1244.4	1243.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8739.8	8735.4	8734.2
4.Wt. of Sample after Evaluation	8255.3	8248.5	8254.4
5.(#3 - #4)	484.5	486.9	479.8
6.#1/#5 =S.G	2.575	2.556	2.591

Standard Deviation =
Range = Average = 2.583x 62.43 = 161.26 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% CB) **Run Date :** May 26, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1256.9	1256.2	1250.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8747.9	8747.2	8741.5
4.Wt. of Sample after Evaluation	8258.5	8258.1	8253.9
5.(#3 - #4)	489.4	489.0	487.6
6.#1/#5 =S.G	2.568	2.569	2.565

Standard Deviation =
Range = Average = 2.567x 62.43 = 160.26 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% CB) **Run Date :** May 23, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1229.4	1227.2	1232.9
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8720.4	8717.2	8723.9
4.Wt. of Sample after Evaluation	8257.4	8256.0	8258.8
5.(#3 - #4)	463.0	462.2	465.1
6.#1/#5 =S.G	2.655	2.655	2.651

Standard Deviation =
Range =

Average = 2.654x 62.43 = 165.69 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% CB) **Run Date :** May 23, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1240.6	1238.2	1239.3
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8731.6	8729.2	8730.3
4.Wt. of Sample after Evaluation	8260.2	8257.2	8258.7
5.(#3 - #4)	471.4	472	471.6
6.#1/#5 =S.G	2.632	2.623	2.628

Standard Deviation =
Range =

Average = 2.628x 62.43 = 164.07 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% CB) **Run Date :** May 23, 19994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1242.0	1237.1	1247.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8733.0	8728.1	8738.5
4.Wt. of Sample after Evaluation	8256.9	8254.3	8260.2
5.(#3 - #4)	476.1	473.8	478.3
6.#1/#5 =S.G	2.609	2.611	2.608

Standard Deviation =
Range = Average = 2.609x 62.43 = 162.88 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% CB) **Run Date :** May 23, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1247.8	1250.2	1242.9
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8738.8	8741.2	8733.9
4.Wt. of Sample after Evaluation	8257.1	8258.4	8256.2
5.(#3 - #4)	481.7	482.8	477.7
6.#1/#5 =S.G	2.590	2.589	2.601

Standard Deviation =
Range = Average = 2.593x 62.43 = 161.88 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% CB) **Run Date :** May 23, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1246.8	1250.8	1247.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8737.8	8741.8	8738.8
4.Wt. of Sample after Evaluation	8253.0	8255.5	8254.8
5.(#3 - #4)	484.8	486.3	484.0
6.#1/#5 =S.G	2.572	2.572	2.578

Standard Deviation =
Range = Average = 2.574x 62.43 = 160.7 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (5% PCB) **Run Date :** Apr. 20, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1224.1	1231.0	1223.7
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8715.1	8722.0	8714.7
4.Wt. of Sample after Evaluation	8250.8	8254.1	8249.8
5.(#3 - #4)	464.3	467.9	464.9
6.#1/#5 =S.G	2.636	2.631	2.632

Standard Deviation =
Range = Average = 2.633x 62.43 = 164.38 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (5 % PCB) **Run Date :** Apr. 20, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1228.9	1243.8	1234.0
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8719.9	8734.8	8725.0
4.Wt. of Sample after Evaluation	8248.5	8259.7	8252.9
5.(#3 - #4)	471.4	475.1	472.1
6.#1/#5 =S.G	2.607	2.617	2.614

Standard Deviation =
Range = Average = 2.616x 62.43 = 2.616 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (5% pcb) **Run Date :** Apr. 20, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1239.1	1218.9	1237.5
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8730.1	8709.9	8728.5
4.Wt. of Sample after Evaluation	8251.4	8238.6	8247.8
5.(#3 - #4)	478.7	471.3	480.8
6.#1/#5 =S.G	2.588	2.586	2.575

Standard Deviation =
Range = Average = 2.583x 62.43 = 161.26 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (5% PCB) **Run Date :** Apr. 20, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1241.9	1243.1	1239.6
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8732.9	8734.1	8730.6
4.Wt. of Sample after Evaluation	8250.3	8250.7	8247.8
5.(#3 - #4)	482.6	483.4	482.8
6.#1/#5 =S.G	2.573	2.572	2.568

Standard Deviation =
Range = Average = 2.571x 62.43 = 160.51 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (5 % PCB) **Run Date :** Apr.20, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1246.6	1244.2	1247.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8737.6	8735.2	8738.7
4.Wt. of Sample after Evaluation	8247.4	8244.5	8246.9
5.(#3 - #4)	490.2	490.7	491.8
6.#1/#5 =S.G	2.543	2.536	2.537

Standard Deviation =
Range = Average = 2.539x 62.43 = 158.51 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% PCB) **Run Date :** Apr.25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1222.8	1241.2	1236.7
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8713.8	8732.2	8727.7
4.Wt. of Sample after Evaluation	8247.2	8257.3	8257.1
5.(#3 - #4)	466.6	474.9	470.6
6.#1/#5 =S.G	2.635	2.632	2.628

Standard Deviation =
Range = Average = 2.632x 62.43 = 164.32 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% PCB) **Run Date :** Apr. 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1237.7	1233.6	1241.4
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8728.7	8724.6	8732.4
4.Wt. of Sample after Evaluation	8256.7	8254.7	8259.5
5.(#3 - #4)	472	469.9	472.9
6.#1/#5 =S.G	2.622	2.625	2.625

Standard Deviation =
Range = Average = 2.624x 62.43 = 163.82 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% PCB) **Run Date :** Apr. 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1239.2	1241.4	1243.2
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8730.2	8732.4	8734.2
4.Wt. of Sample after Evaluation	8253.3	8253.7	8253.9
5.(#3 - #4)	476.9	478.7	480.3
6.#1/#5 =S.G	2.598	2.593	2.588

Standard Deviation =
Range = Average = 2.593x 62.43 = 161.88 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% PCB) **Run Date :** Apr. 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1247.6	1248.2	1247.8
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8738.6	8739.2	8738.8
4.Wt. of Sample after Evaluation	8247.7	8248.3	8248.7
5.(#3 - #4)	490.9	490.9	490.1
6.#1/#5 =S.G	2.541	2.543	2.546

Standard Deviation =
Range = Average = 2.543x 62.43 = 158.76 lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (10% PCB) **Run Date :** Apr. 25, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1256.4	1245.6	1251.4
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8747.4	8736.6	8742.4
4.Wt. of Sample after Evaluation	8249.2	8242.8	8247.2
5.(#3 - #4)	498.2	493.8	495.2
6.#1/#5 =S.G	2.522	2.522	2.527

Standard Deviation =
Range = Average = 2.524x 62.43 = 157.57 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC- **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% PCB) **Run Date :** Apr. 28, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1228.4	1231.5	1235.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8719.4	8722.5	8726.1
4.Wt. of Sample after Evaluation	8255.1	8258.2	8257.2
5.(#3 - #4)	464.3	464.3	467.6
6.#1/#5 =S.G	2.646	2.652	2.641

Standard Deviation =
Range = Average = 2.646x 62.43 = 165.19 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% PCB) **Run Date :** Apr. 28, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1233.8	1238.2	1242.5
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8724.8	8729.2	8733.5
4.Wt. of Sample after Evaluation	8253.0	8252.9	8257.2
5.(#3 - #4)	471.8	476.3	476.3
6.#1/#5 =S.G	2.615	2.600	2.609

Standard Deviation =
Range = Average = 2.609x 62.43 = 162.88 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% PCB) **Run Date :** Apr. 28, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1243.3	1243.3	1243.7
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8734.3	8734.3	8734.7
4.Wt. of Sample after Evaluation	8251.8	8253.9	8252.1
5.(#3 - #4)	482.5	480.4	482.6
6.#1/#5 =S.G	2.578	2.588	2.577

Standard Deviation =
Range = Average = 2.581x 62.43 = 161.13 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% PCB) **Run Date :** Apr. 28, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1250.5	1246.2	1248.5
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8741.5	8737.2	8739.5
4.Wt. of Sample after Evaluation	8250.8	8246.7	8257.5
5.(#3 - #4)	490.7	490.5	483.1
6.#1/#5 =S.G	2.548	2.541	2.584

Standard Deviation =
Range = Average = 2.545x 62.43 = 158.88 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (15% PCB) **Run Date :** Apr. 28, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1252.8	1253.6	1252.0
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8743.8	8744.6	8743.0
4.Wt. of Sample after Evaluation	8255.2	8256.1	8255.3
5.(#3 - #4)	488.6	488.5	487.7
6.#1/#5 =S.G	2.564	2.566	2.567

Standard Deviation =
Range = Average = 2.566x 62.43 = 160.2 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

LABORATORY TEST PROCEDURE FOR MAXIMUM THEORETICAL SPECIFIC GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% PCB) **Run Date :** May 10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	3.5 - 1	3.5 - 2	3.5 - 3
1.Wt. of Sample (g)	1228.8	1234.3	1230.0
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8719.8	8725.3	8721
4.Wt. of Sample after Evaluation	8256.5	8261.1	8257.2
5.(#3 - #4)	463.3	464.2	463.8
6.#1/#5 =S.G	2.652	2.569	2.652

Standard Deviation =
Range = Average = 2.645x 62.43 = 165.13 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% PCB) **Run Date :** May 10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4 - 1	4 - 2	4 - 3
1.Wt. of Sample (g)	1242.9	1241.1	1243.1
2.Wt.of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8733.9	8732.1	8734.1
4.Wt. of Sample after Evaluation	8258.4	8258.4	8258.7
5.(#3 - #4)	475.5	473.7	475.4
6.#1/#5 =S.G	2.619	2.620	2.615

Standard Deviation =
Range = Average = 2618x 62.43 = 163.44 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% PCB) **Run Date :** May 10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	4.5 - 1	4.5 - 2	4.5 - 3
1.Wt. of Sample (g)	1243.2	1244.7	1250.5
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8734.2	8735.7	8741.5
4.Wt. of Sample after Evaluation	8256.2	8256.2	8260.1
5.(#3 - #4)	478.0	479.5	481.4
6.#1/#5 =S.G	2.601	2.596	2.598

Standard Deviation =
Range = Average = 2.598x 62.43 = 162.19 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% PCB) **Run Date :** May 10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5 - 1	5 - 2	5 - 3
1.Wt. of Sample (g)	1249.3	1253.5	1249.2
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8740.3	8744.5	8740.2
4.Wt. of Sample after Evaluation	8259.4	8262.2	8252.8
5.(#3 - #4)	480.9	482.3	487.4
6.#1/#5 =S.G	2.598	2.599	2.563

Standard Deviation =
Range = Average = 2.581x 62.43 = 161.13 lbs/ft^3

LABORATORY TEST PROCEDURE
FOR
MAXIMUM THEORETICAL SPECIFIC
GRAVITY OF COMPACTED SPECIMEN

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 (20% PCB) **Run Date :** May 10, 1994
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.	5.5 - 1	5.5 - 2	5.5 - 3
1.Wt. of Sample (g)	1256.9	1254.3	1254.0
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2	8747.9	8745.3	8745.0
4.Wt. of Sample after Evaluation	8257.7	8255.8	8257.0
5.(#3 - #4)	490.2	489.5	487.9
6.#1/#5 =S.G	2.564	2.562	2.570

Standard Deviation =
Range = Average = 2.560x 62.43 = 159.82 lbs/ft^3

Laboratory : Indiana Department of Transportation Division of Research Lab.
Type of Mix : AC-20 **Run Date :** Jun.
Tested by : TAESOON PARK

PYCNOMETER SPECIFIC GRAVITY DETERMINATION

Specimen I.D.			
1.Wt. of Sample (g)			
2.Wt of Pyc.+ Water	7491.0	7491.0	7491.0
3.Wt. of #1+#2			
4.Wt. of Sample after Evaluation			
5.(#3 - #4)			
6.#1/#5 =S.G			

Standard Deviation =
Range = Average = x 62.43 = lbs/ft^3

APPENDIX D

Summary of the Marshall Test Results and Mixture Properties

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
PCB Content : 0%
Date Tsted : May 27 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1222.2	724.2	1235.1		2.392	2.634				2675	
2	3.5	1224	722.6	1236.7		2.381	2.633				2775	
3	3.5	1230.5	727	1241.9		2.390	2.627				2600	
Average						2.388	2.631	9.2	14.3	35	2683	10
1	4	1234.2	727.1	1242.7		2.394	2.604				2650	
2	4	1232.3	727.4	1238.7		2.410	2.604				2950	
3	4	1231.4	727.1	1239.1		2.405	2.595				2785	
Average						2.403	2.601	7.8	14.2	46.5	2795	11.6
1	4.5	1245.2	734.1	1250.5		2.411	2.594				2650	
2	4.5	1246.3	736.3	1251.2		2.420	2.593				2550	
3	4.5	1240.2	735	1243.8		2.438	2.593				2250	
Average						2.423	2.593	6.8	13.9	52.5	2483	13.5
1	5	1243.6	734.2	1247.8		2.421	2.565				2200	
2	5	1243.7	735.7	1246.4		2.435	2.582				2200	
3	5	1243.6	736	1246.4		2.437	2.563				2160	
Average						2.426	2.570	5.6	14.3	60.8	2187	14
1	5.5	1236.2	731.3	1237.9		2.440	2.548				1900	
2	5.5	1253.6	743.9	1255.4		2.451	2.548				2125	
3	5.5	1254.5	742.5	1256.1		2.443	2.549				2250	
Average						2.445	2.548	4.1	14	70.7	2092	14.6

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
PCB Content : 5%
Date Tsted : June 2 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1225.1	724.5	1236.6		2.392	2.642				2675	
2	3.5	1230.3	728.5	1241.3		2.399	2.636				2350	
3	3.5	1234.6	729.6	1247.9		2.382	2.630				2525	
Average						2.391	2.636	9.3	14.2	34.5	2517	10
1	4	1242	731.1	1248.1		2.402	2.621				2200	
2	4	1235	728	1242.5		2.400	2.616				2150	
3	4	1240.6	734	1246.3		2.422	2.615				2225	
Average						2.408	2.617	8.0	14	42.9	2192	11.5
1	4.5	1242.4	732.9	1245.8		2.422	2.586				2500	
2	4.5	1236.3	727.7	1241.2		2.408	2.593				2425	
3	4.5	1243.3	730.7	1248.4		2.402	2.584				2400	
Average						2.410	2.588	6.8	14.4	52.1	2442	12.6
1	5	1242.2	730.1	1244.8		2.413	2.565				2125	
2	5	1243.3	732.2	1246.8		2.416	2.580				2250	
3	5	1247	735.1	1249.7		2.423	2.565				2250	
Average						2.417	2.570	6.0	14.7	59.2	2208	14.5
1	5.5	1250.6	735.4	1253.3		2.415	2.552				2100	
2	5.5	1250.1	737.5	1253.8		2.421	2.555				2125	
3	5.5	1247	734.1	1250.8		2.413	2.553				2080	
Average						2.416	2.553	5.4	15.1	64.2	2102	14.6

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
PCB Content : 10%
Date Tsted : June 2 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1232.6	730.4	1246.9		2.386	2.642				2250	
2	3.5	1233	731.7	1245.4		2.400	2.636				2350	
3	3.5	1231.1	726.9	1246.2		2.371	2.630				2300	
Average						2.386	2.636	9.5	14.3	33.6	2300	11.9
1	4	1236.2	730.2	1244.7		2.403	2.621				2330	
2	4	1240.2	734	1248.2		2.412	2.616				2315	
3	4	1240.4	734.9	1251.3		2.402	2.615				2380	
Average						2.408	2.617	8.0	14	42.9	2342	12.5
1	4.5	1243.2	722.4	1253.7		2.340	2.586				2220	
2	4.5	1246.8	730.9	1253.8		2.384	2.593				2226	
3	4.5	1245.2	728.3	1252.3		2.376	2.584				2245	
Average						2.367	2.588	8.5	14.4	52.1	2230	13.5
1	5	1250	737.2	1254.4		2.417	2.565				2262	
2	5	1247.6	730.4	1252.2		2.391	2.560				2268	
3	5	1241.3	733.3	1244.5		2.428	2.565				2256	
Average						2.411	2.570	6.2	14.9	58.4	2262	14
1	5.5	1251.5	746.7	1255		2.462	2.552				2250	
2	5.5	1250.5	740.9	1253		2.442	2.555				2250	
3	5.5	1246	738.3	1248.6		2.442	2.553				2050	
Average						2.449	2.553	4.1	13.9	70.5	2183	15

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
PCB Content : 15%
Data Tsted : June 7 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1229.3	728.2	1250.1		2.355	2.652				2359	
2	3.5	1230.8	728.9	1252.4		2.351	2.641				2390	
3	3.5	1233.7	732.1	1252.6		2.370	2.646				2420	
Average						2.359	2.648	10.9	15.3	28.8	2390	11
1	4	1239.8	732.5	1252.8		2.383	2.622				2384	
2	4	1240	730	1253		2.371	2.621				2400	
3	4	1237.1	730.2	1252.7		2.368	2.621				2365	
Average						2.374	2.621	9.4	15.2	38.2	2383	12
1	4.5	1245.6	730.1	1254.7		2.374	2.612				2260	
2	4.5	1240.9	729.5	1247.8		2.394	2.604				2240	
3	4.5	1244.1	732.7	1251.7		2.397	2.603				2249	
Average						2.389	2.606	8.4	15.2	44.7	2250	13.3
1	5	1249.3	734.8	1255.8		2.398	2.585				2350	
2	5	1249.3	736.8	1254.4		2.414	2.584				2360	
3	5	1251.3	736.3	1255.9		2.408	2.587				2345	
Average						2.417	2.585	6.5	14.7	55.8	2352	13.7
1	5.5	1256.4	739.2	1259.5		2.415	2.571				2500	
2	5.5	1254.2	739.1	1257.4		2.420	2.573				2459	
3	5.5	1250.7	738.1	1253.8		2.425	2.559				2450	
Average						2.416	2.568	5.9	15.1	60.9	2470	14.1

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
PCB Content : 20%
Data Tsted : June 7 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in 2	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1232.1	729.3	1255.5		2.342	2.653				2265	
2	3.5	1232.1	731.8	1252.5		2.366	2.653				2250	
3	3.5	1231.9	731	1256.3		2.345	2.654				2250	
Average						2.351	2.653	11.4	14.7	32	2255	11
1	4	1244.8	734.5	1259.4		2.371	2.629				2200	
2	4	1237	731.7	1255.3		2.362	2.631				2150	
3	4	1244.7	733.9	1260.4		2.364	2.632				2185	
Average						2.366	2.631	10.1	14.6	41.1	2178	12
1	4.5	1242.8	730.4	1253.9		2.374	2.616				2120	
2	4.5	1242.1	732	1252.3		2.387	2.613				2145	
3	4.5	1242.1	732.8	1253.8		2.384	2.617				2110	
Average						2.382	2.615	8.9	14.1	48.9	2125	13
1	5	1252	738.5	1259.2		2.395	2.597				2440	
2	5	1247.8	733.5	1255.9		2.389	2.595				2380	
3	5	1251	739	1259.1		2.405	2.601				2380	
Average						2.395	2.598	7.8	14.2	58.5	2400	14
1	5.5	1257.5	737.2	1262.2		2.395	2.581				2400	
2	5.5	1254.2	737.8	1259.8		2.403	2.582				2410	
3	5.5	1256.5	743.5	1260.5		2.430	2.577				2410	
Average						2.409	2.580	6.8	14.3	65	2407	14

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
CARBON BLACK Content :5%
Date Tsted :June 10 1994   Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1227.6	724.2	1244		2.362	2.640				2250	
2	3.5	1226.8	727.2	1241.6		2.385	2.642				2250	
3	3.5	1224.2	725.8	1239.9		2.381	2.642				2240	
Average						2.376	2.641	10.0	14.7	32	2247	12.8
1	4	1237.9	727	1245.3		2.388	2.617				2275	
2	4	1238	729.9	1246.7		2.396	2.618				2300	
3	4	1238	735.3	1243.2		2.437	2.613				2300	
Average						2.392	2.616	8.6	14.6	41.1	2292	13.2
1	4.5	1241.5	730.4	1247.3		2.402	2.599				2250	
2	4.5	1239.7	735.1	1244		2.436	2.602				2200	
3	4.5	1231.5	726.6	1241.5		2.392	2.623				2450	
Average						2.419	2.608	7.2	14.1	48.9	2300	13.4
1	5	1242.7	735.6	1247.3		2.429	2.582				2440	
2	5	1240.4	733.7	1244.6		2.428	2.583				2425	
3	5	1240.8	736	1245.2		2.437	2.583				2300	
Average						2.431	2.583	5.9	14.2	58.5	2389	13.8
1	5.5	1241.9	736	1246.4		2.433	2.568				2100	
2	5.5	1247.8	740	1251.2		2.441	2.563				2100	
3	5.5	1244.8	734.8	1249.1		2.420	2.567				2300	
Average						2.437	2.566	5.0	14.3	65	2167	14

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
CARBON BLACK Content : 10%
Date Tsted :June 12 1994   Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1237.9	732.5	1252.8		2.379	2.643				2395	
2	3.5	1234.7	730.7	1252.4		2.367	2.642				2400	
3	3.5	1234.4	728.6	1246.7		2.383	2.645				2350	
Average						2.376	2.643	10.1	14.7	31.3	2382	12.8
1	4	1238.9	728.7	1247.8		2.367	2.624				2413	
2	4	1234.3	727.8	1243.7		2.393	2.628				2375	
3	4	1239.9	728.7	1248.7		2.384	2.622				2450	
Average						2.392	2.625	8.9	14.6	39	2413	13
1	4.5	1233.7	726.2	1240		2.401	2.611				2350	
2	4.5	1229.7	721.5	1236.1		2.390	2.609				1950	
3	4.5	1244.4	735.6	1247.9		2.429	2.604				2360	
Average						2.419	2.608	7.2	14.1	48.9	2355	13.2
1	5	1244.9	735.9	1249.4		2.424	2.589				2240	
2	5	1250.5	742.5	1254.7		2.441	2.588				2100	
3	5	1243.9	735.5	1247.6		2.429	2.588				.	
Average						2.431	2.588	6.1	14.2	57	2295	13.7
1	5.5	1243.7	737.1	1247.1		2.439	2.571				2375	
2	5.5	1251.2	742.1	1253.7		2.446	2.568				2300	
3	5.5	1251.9	742.9	1254.5		2.447	2.567				2150	
Average						2.437	2.569	5.1	14.3	64.3	2275	13.9

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
CARBON BLACK Content : 15%
Date Tsted : June 14 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)		Flow
1	3.5	1238.6	732.6	1258.3		2.356	2.643				2400		
2	3.5	1233.1	730.5	1250.7		2.370	2.650				2475		
3	3.5	1232.5	729.2	1252.7		2.354	2.644				2375		
Avaraga						2.360	2.646	10.8	15.3	29.4	2417		12.8
1	4	1240.2	730.9	1251.3		2.383	2.628				2625		
2	4	1238.1	729.2	1252.3		2.367	2.631				2525		
3	4	1235.7	726.8	1247.8		2.372	2.631				2500		
Average						2.373	2.630	9.8	15.3	36	2550		13
1	4.5	1233.3	725.3	1239.9		2.397	2.612				2800		
2	4.5	1233.5	726.6	1240.8		2.399	2.616				2550		
3	4.5	1244.4	734.6	1250.4		2.413	2.606				2625		
Averaga						2.403	2.611	8.0	14.7	45.8	2659		13.2
1	5	1247.3	736.5	1251.9		2.420	2.594				2525		
2	5	1246.3	736.9	1251		2.424	2.593				2600		
3	5	1244.4	733.5	1248.5		2.416	2.592				2490		
Avarege						2.420	2.593	6.7	14.6	54.1	2539		13.4
1	5.5	1254.3	743.6	1258.2		2.437	2.574				2450		
2	5.5	1249.7	738.6	1255		2.420	2.578				2550		
3	5.5	1254.7	740.3	1258.3		2.422	2.570				2850		
Average						2.426	2.574	5.7	14.7	61.2	2500		13.6

Test Results and Mix Properties for Marshall Mix Design
AC-10, 75 blows,
CARBON BLACK Content : 20%
Date Tsted : June 14 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)		Flow
1	3.5	1226.3	727.5	1252.2		2.337	2.655			·			
2	3.5	1226.3	727.5	1252.5		2.336	2.655				2575		
3	3.5	1229.9	731.5	1252.4		2.361	2.655				2725		
Averaga						2.360	2.655	11.1	15.3	27.5	2600		12
1	4	1242.4	733.3	1257.3		2.371	2.630				2750		
2	4	1239.1	734.4	1257.6		2.368	2.628				2575		
3	4	1232.9	727.9	1248.6		2.368	2.626				2590		
Average						2.369	2.628	9.9	15.4	35.7	2689		12.5
1	4.5	1240.2	729	1249		2.385	2.613				2550		
2	4.5	1243.3	734.8	1252.4		2.402	2.610				2300		
3	4.5	1244	733.6	1250.2		2.408	2.612				2560		
Average						2.398	2.612	8.2	14.9	45	2470		12.7
1	5	1250.4	735.9	1256.9		2.400	2.590				2425		
2	5	1248.6	737.2	1254.3		2.415	2.593				2300		
3	5	1248.5	736	1253.5		2.413	2.590				2375		
Average						2.409	2.591	7.0	15	53.3	2367		13
1	5.5	1249.9	738.6	1253.8		2.426	2.577				2250		
2	5.5	1249.8	741.1	1253.3		2.440	2.573				2225		
3	5.5	1251.7	745.7	1254.7		2.459	2.576				2125		
Average						2.420	2.575	6.0	14.9	59.7	2200		13.5

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
PCB Content : 0 %
Date Tsted :March 17, 1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1222.7	723.5	1236.3		2.384	2.635				2650	
2	3.5	1228.2	723.8	1240.8		2.376	2.610				2790	
3	3.5	1232.8	728.1	1246.7		2.377	2.591				2500	
Average						2.379	2.612	8.9	14.6	39	2648	11.8
1	4	1228.8	724.9	1234.8		2.410	2.563				2625	
2	4	1239.9	730.7	1245.3		2.409	2.594				2650	
3	4	1236.4	728.8	1244.9		2.400	2.592				2675	
Average						2.410	2.583	6.7	14	52.1	2725	13.2
1	4.5	1237.6	731.4	1241.7		2.425	2.559				2975	
2	4.5	1234.7	726.7	1238.7		2.412	2.534				2690	
3	4.5	1239.5	732	1242.7		2.427	2.528				2975	
Average						2.421	2.540	4.7	14.1	66.7	2792	13.8
1	5	1243.2	736.4	1247		2.435	2.492				2175	
2	5	1239.1	734.2	1242.8		2.436	2.494				2225	
3	5	1239.9	731.9	1243.4		2.424	2.494					
Average						2.432	2.493	2.5	14.2	82.4	2200	15.3
1	5.5	1246.3	739.1	1249.3		2.443	2.462				2060	
2	5.5	1251	741.3	1254.2		2.439	2.467				1970	
3	5.5	1252.3	739.9	1254.7		2.433	2.471				1900	
Average						2.438	2.467	1.2	14.3	91.6	1977	19

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
PCB Content :5 %
Date Tsted : Aor.20 1994 Tested by :Taesoon Park

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Voluma(cm3)	Bulk Specific Gravity	Max.Theor S.G.	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1227.8	725	1243.9		2.366	2.636				2375	-
2	3.5	1233.4	731.2	1247.8		2.387	2.631				2200	
3	3.5	1228.3	726.7	1244.2		2.373	2.632				2375	
Average		1229.8				2.375	2.633	9.8	14.7	33.3	2317	12.6
1	4	1241.5	731.4	1248.6		2.4	2.607				2550	
2	4	1239.2	732.5	1249.2		2.398	2.617				2425	
3	4	1236.2	730.4	1244.3		2.4	2.614				2425	
Average		1239.0				2.4	2.616	8.3	14.3	42	2467	13.8
1	4.5	1240.9	729.2	1245.1		2.405	2.588				2550	
2	4.5	1222.4	717.5	1226.3		2.403	2.586				2425	
3	4.5	1241.2	732.6	1245.9		2.418	2.575				2275	
Average		1234.8				2.409	2.583	6.7	14.5	53.8	2417	12.4
1	5	1245.4	737.3	1248.8		2.435	2.573				2300	
2	5	1243.9	734.8	1247.7		2.425	2.572				2225	
3	5	1244.4	735.2	1248.2		2.426	2.568				2225	
Average		1244.6				2.429	2.571	5.5	14.3	61.5	2250	12.2
1	5.5	1250	741.6	1253.1		2.444	2.543				1900	
2	5.5	1248.3	740	1251.4		2.44	2.536				1950	
3	5.5	1251	740	1253.7		2.435	2.537				2000	
Average		1249.8				2.44	2.539	3.9	14.2	72.5	1925	15.4

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
PCB Content : 10 %
Date Tsted : Apr.25 1994, Tested by : Taesoon Park

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1230.5	728.7	1250.5		2.358	2.635				2275	
2	3.5	1232.2	730.3	1251.3		2.365	2.632				2300	
3	3.5	1234.2	729.9	1251.1		2.368	2.628				2200	
Average						2.364	2.632	10.2	15.1	32.5	2425	13
1	4	1237.7	730	1250		2.380	2.622				2600	
2	4	1235.8	727.8	1248.1		2.375	2.625					
3	4	1243 4	732.8	1256.1		2.378	2.625				2375	
Average						2.377	2.598	8.5	15.1	43.7	2488	12.9
1	4.5	1241	728 4	1247.8		2.389	2.598				2575	
2	4.5	1244 4	732.8	1251.6		2.399	2.593				2425	
3	4.5	1247.3	734.8	1254.1		2.402	2.588				2430	
Average						2.397	2.593	7.8	14.9	49	2477	14.2
1	5	1250.7	736 4	1256.1		2.407	2.541				2250	
2	5	1251.1	738.3	1255.6		2.418	2.543				2350	
3	5	1248.5	734 4	1253.8		2.404	2.546				2450	
Average						2.409	2.543	5.3	15	64.7	2325	13.2
1	5.5	1258.8	741.4	1262.2		2.417	2.522				1900	
2	5.5	1249.7	739.6	1253.8		2.431	2.522				2000	
3	5.5	1252 4	740.5	1255.6		2.431	2.527				2375	
Average						2.427	2.524	3.6	14.7	73.5	2092	14.6

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
PCB Content : 15 %
Data Tsted : Apr. 26 1994, Tested by : Taesson Park

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1229.8	730.3	1249.8		2.367	2.646				2400	
2	3.5	1232.7	732.5	1252.5		2.371	2.652				2575	
3	3.5	1237.9	733.8	1257.8		2.362	2.641				2500	
Average						2.367	2.646	10.6	15	29.3	2492	10.6
1	4	1237.2	729.1	1254.7		2.354	2.615				2415	
2	4	1239.6	731.6	1254.8		2.369	2.602				2525	
3	4	1244.5	734.1	1256.2		2.384	2.609				2950	
Average						2.369	2.609	9.2	15 4	40.3	2580	12 4
1	4.5	1244.1	731.8	1254 4		2.381	2.578				2600	
2	4.5	1243.5	732.3	1254 4		2.382	2.588				2450	
3	4.5	1244.6	731.5	1252.6		2.388	2.577				2520	
Average						2.384	2.581	7.6	15 4	50	2599	11.2
1	5	1250.2	733.7	1256.3		2.392	2.564				2550	
2	5	1249 4	732.2	1256		2.385	2.566				2450	
3	5	1252.7	738	1257.7		2.410	2.567				2515	
Average						2.396	2.566	6.6	15.4	57.1	2505	14.6
1	5.5	1251	737.2	1254.8		2.417	2.548				2500	
2	5.5	1254.5	738.6	1259.3		2.409	2.541				2450	
3	5.5	1254.1	737.5	1258.7		2.406	2.548				2500	
Average						2.411	2.546	5.3	15.2	65.1	2230	13.6

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
PCB Content : 20 %
Data Tsted : May 10 1994, Tested by :Taesoon Park

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1233	730.8	1259.4		2.333	2.652				2500	
2	3.5	1238.9	731.9	1260.5		2.344	2.659				2500	
3	3.5	1235.7	730.2	1257.4		2.344	2.652				2625	
Average						2.340	2.654	11.6	16	26.3	2542	12.6
1	4	1249.3	736.7	1262.1		2.378	2.619				2675	
2	4	1242.3	733.7	1261.6		2.353	2.620				2725	
3	4	1245.2	735.9	1260.9		2.372	2.615				2625	
Average						2.368	2.618	9.6	15.5	38.1	2675	12.4
1	4.5	1245.3	732.9	1255.6		2.382	2.601				2675	
2	4.5	1246.1	735.1	1257.4		2.386	2.596				2735	
3	4.5	1252.2	738.9	1265.1		2.360	2.598				2625	
Average						2.383	2.598	8.3	15.4	46.1	2675	12.4
1	5	1251.4	734.6	1258.3		2.390	2.581				2650	
2	5	1255	738.2	1262.3		2.395	2.582				2425	
3	5	1251.1	736	1257.1		2.401	2.581				2300	
Average						2.395	2.581	7.2	15.5	53.5	2600	12.4
1	5.5	1259.6	741.1	1264.8		2.405	2.564				2500	
2	5.5	1256	742.7	1261.6		2.421	2.562				2450	
3	5.5	1255.7	738.7	1259.9		2.409	2.570					
Average						2.412	2.565	6.0	15.2	60.5	2459	13.8

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
CARBON BLACK Content : 10%
Date Tsted :5/16/1994 Tested by :TAESOON PARK

Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1227.8	724.8	1242.7		2.371	2.626				2250	
2	3.5	1237.6	732.7	1253.5		2.376	2.624				2300	
3	3.5	1232.2	729.5	1250.3		2.366	2.630					
Average						2.371	2.627	9.7	14.9	34.9	2275	12.3
1	4	1237.4	730.2	1248.5		2.387	2.624				2500	
2	4	1235.9	729.1	1248.9		2.378	2.619				2425	
3	4	1240.4	731.6	1251.2		2.387	2.610				2350	
Average						2.384	2.618	8.9	14.9	40.3	2425	13.4
1	4.5	1241	737.2	1245.6		2.441	2.582				2590	
2	4.5	1244.5	736.4	1249.5		2.425	2.589				2375	
3	4.5	1237	727.2	1243		2.398	2.587				1950	
Average						2.412	2.586	6.7	14.4	53.5	2483	14.4
1	5	1240.7	733.6	1244.8		2.427	2.570				2390	
2	5	1250.5	740.6	1254.4		2.434	2.571				2150	
3	5	1247.3	732.4	1250.8		2.406	2.572				2240	
Average						2.431	2.571	5.4	14.2	62	2260	14.1
1	5.5	1250.8	739.8	1253.5		2.435	2.555				2090	
2	5.5	1250.8	741.1	1253.7		2.440	2.559				2090	
3	5.5	1249.6	741.7	1252.9		2.444	2.558				2090	
Average						2.440	2.557	4.6	14.2	67.6	2090	15.6

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
CARBON BLACK Content : 15%
Date Tsted :5/24/1994 Tested by :TAESOON PARK

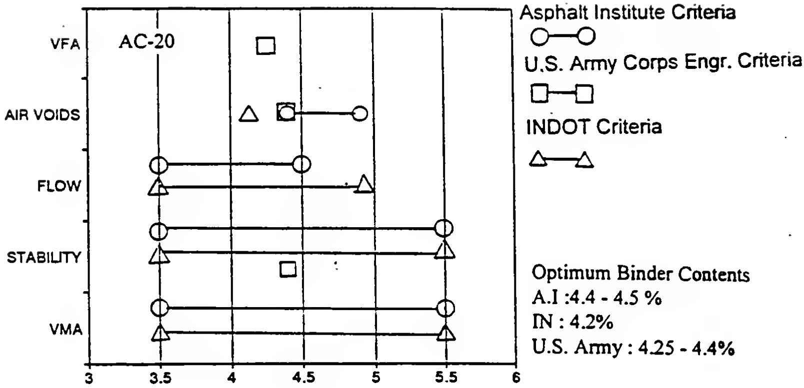
Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Voluma(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1233.8	732.2	1253.7		2.366	2.646				2275	
2	3.5	1233.3	732.3	1253.6		2.366	2.643				2450	
3	3.5	1228.5	729.8	1247.6		2.373	2.636				2425	
Average						2.368	2.642	10.4	15	30.7	2380	12.2
1	4	1239.6	733.9	1249.8		2.403	2.636				2600	
2	4	1236.6	733.2	1247.6		2.404	2.635				2625	
3	4	1242.1	734.3	1253.2		2.394	2.622				2150	
Average						2.400	2.631	8.8	14.3	38.5	2455	13.5
1	4.5	1236.9	730.8	1242.8		2.416	2.608				2150	
2	4.5	1235.6	730.2	1241.5		2.417	2.610				2150	
3	4.5	1236.9	724.3	1241.1		2.393	2.603				2300	
Average						2.409	2.607	7.6	14.5	47.6	2575	14.9
1	5	1248.4	741.5	1255.1		2.431	2.575				2450	
2	5	1244.9	738.2	1255.5		2.407	2.556				2350	
3	5	1244.1	737.9	1248.7		2.436	2.591				2650	
Average						2.425	2.583	6.1	14.4	57.6	2484	13.2
1	5.5	1258.3	744.2	1261.4		2.433	2.568				2350	
2	5.5	1256.2	742.1	1259.5		2.428	2.569				2325	
3	5.5	1252.7	743.8	1256.6		2.443	2.565				2375	
Average						2.435	2.567	5.2	14.4	63.9	2350	14.8

Test Results and Mix Properties for Marshall Mix Design
AC-20, 75 blows,
CARBON BLACK Content :20%
Date Tsted : May 19, 1994 Tested by :TAESOON PARK

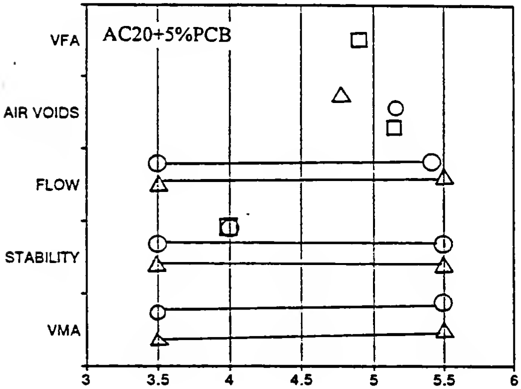
Sample No.	Asphalt Content	Weight in Air (g)	Weight in Water (g)	SSD(g)	Volume(cm3)	Bulk Specific Gravity	Max.Theor Gravity	Air Void (%)	VMA	Voids Filled	Measured Stability(lb)	Flow
1	3.5	1230.3	731.2	1250.8		2.368	2.655				2600	
2	3.5	1227.8	731	1251.1		2.361	2.655				2375	
3	3.5	1234	729.9	1256.5		2.343	2.651				2325	
Average						2.357	2.654	11.2	15.4	27.3	2350	15
1	4	1241.2	733.1	1256.6		2.371	2.632				2300	
2	4	1239.3	734.9	1256.6		2.376	2.623				2450	
3	4	1240.2	735	1255.2		2.384	2.628				2300	
Average						2.377	2.628	9.5	15.1	37.1	2375	15.6
1	4.5	1242.4	733.2	1251.4		2.398	2.609				2350	
2	4.5	1237.1	727.6	1246.4		2.385	2.611				2425	
3	4.5	1248.4	738.8	1255.7		2.415	2.608				2550	
Average						2.399	2.609	8.1	14.8	45.3	2442	15.8
1	5	1248.3	737.9	1253.3		2.422	2.590				2550	
2	5	1250.3	732.3	1256.7		2.384	2.598				2475	
3	5	1243.6	739.5	1246		2.446	2.601				2350	
Average						2.434	2.596	6.3	14.1	55.3	2458	16.4
1	5.5	1247.4	736.4	1255.2		2.404	2.572				2150	
2	5.5	1251.6	738.4	1255		2.423	2.572				2275	
3	5.5	1248.2	738.7	1252.9		2.427	2.578				2500	
Average						2.421	2.574	5.9	14.9	60.4	2200	18

APPENDIX E

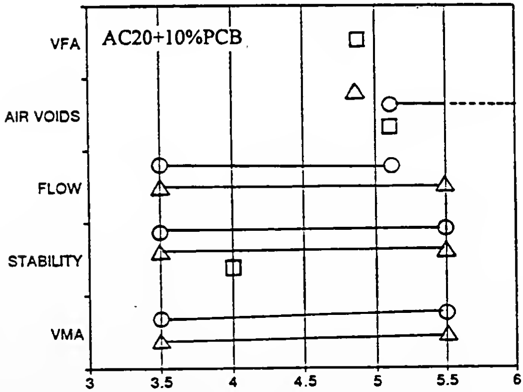
Determination of Optimum Binder Contents



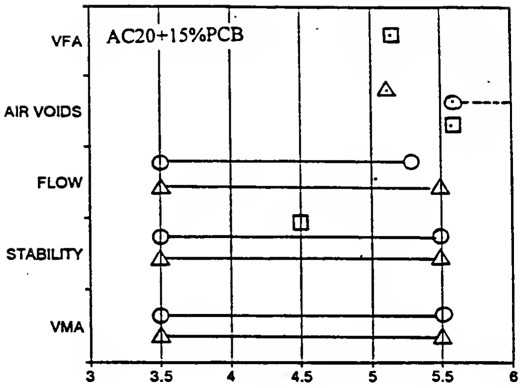
Optimum Binder Contents
A.I :4.4 - 4.5 %
IN : 4.2%
U.S. Army : 4.25 - 4.4%



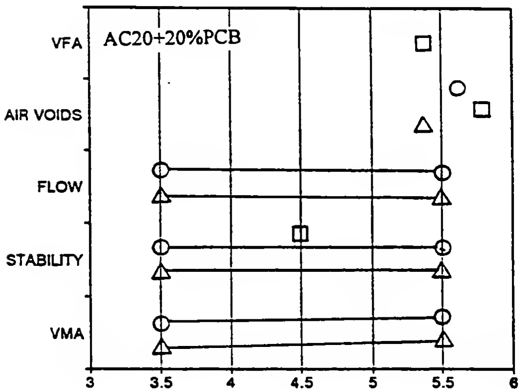
A.I :5.2 - 5.4 %
IN : 4.7%
U.S. Army : 4.68%



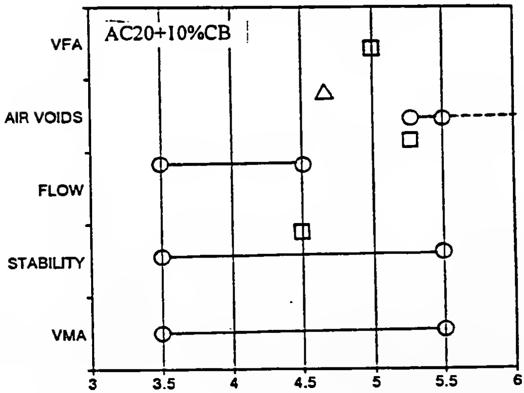
A.I :5.15 %
IN : 4.8%
U.S. Army : 4.75%



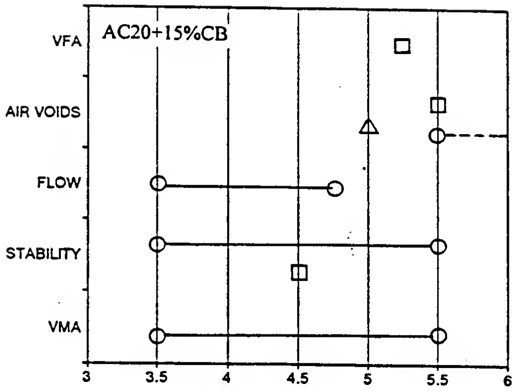
A.I :N/A
IN : 5.2%
U.S. Army : 5.1%



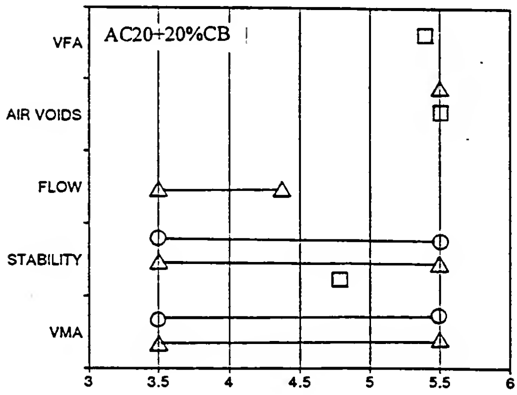
A.I :N/A
IN : 5.45%
U.S. Army : 5.2%



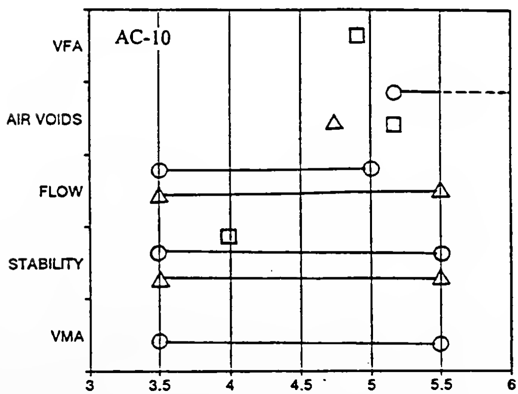
A.I :N/A
IN : 4.7%
U.S. Army : 4.9%



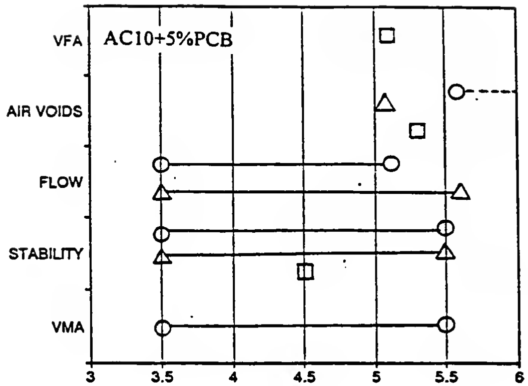
A.I :N/A
IN : 5%
U.S. Army : 5.1%



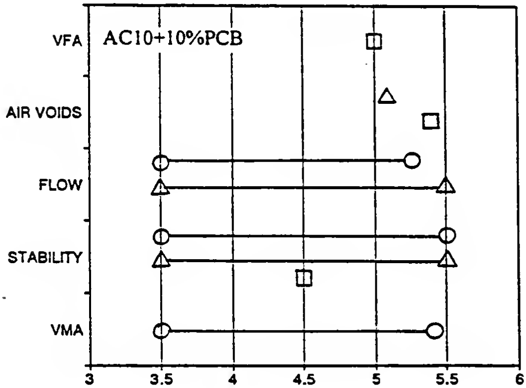
A.I :N/A
IN : 5.5%
U.S. Army : 5.2%



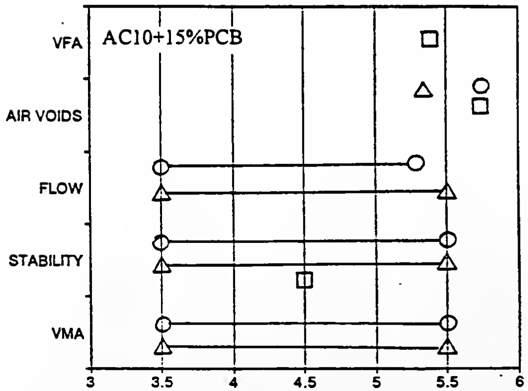
A.I :N/A
IN : 5.5%
U.S. Army : 5.2%



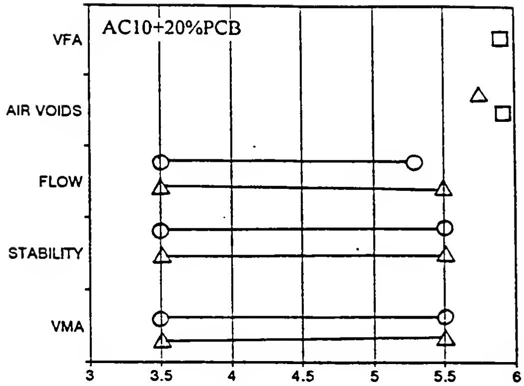
A.I :N/A
IN : 4.8%
U.S. Army : 4.7%



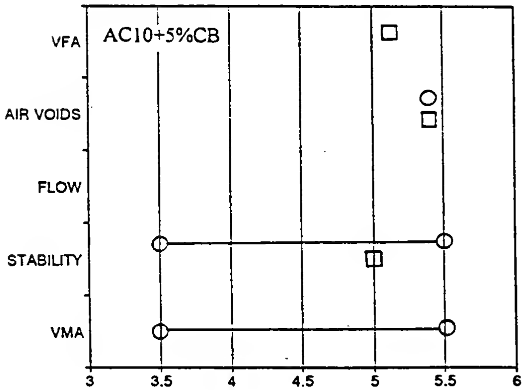
A.I :N/A
IN : 5%
U.S. Army : 4.9%



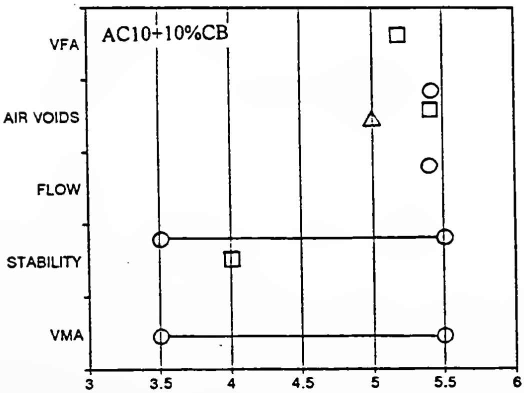
A.I :N/A
IN : 5.1%
U.S. Army : 5%



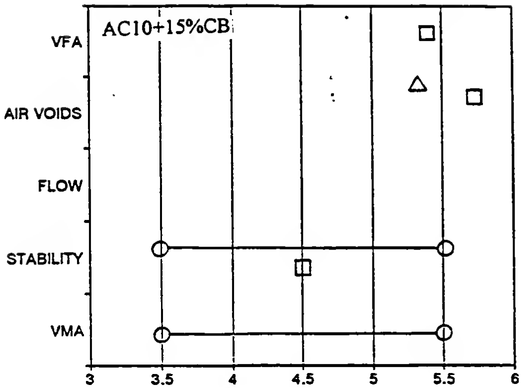
A.I :N/A
IN : 5.4%
U.S. Army : 5.2%



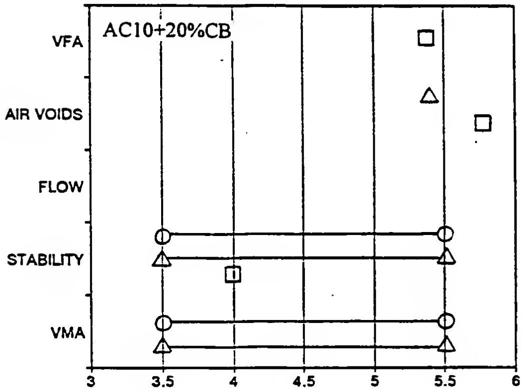
A.I :N/A
IN : 5.7%
U.S. Army : 5.5%



A.I :N/A
IN : 5%
U.S. Army : 5.2%



A.I :N/A
IN : 5.3%
U.S. Army : 5.2%



A.I :N/A
IN : 5.4%
U.S. Army : 5.2%

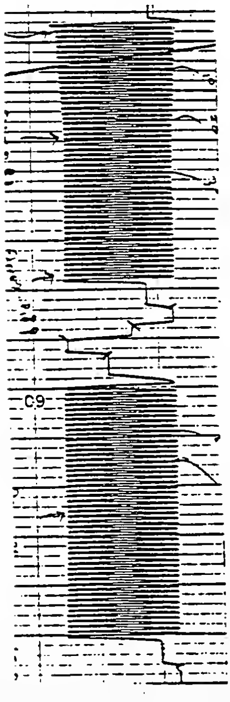
APPENDIX F

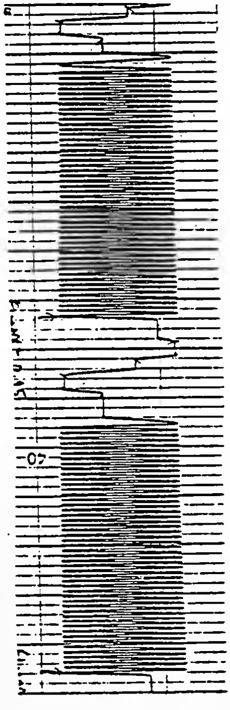
Gyratory Testing Machine Data and Gyrograph

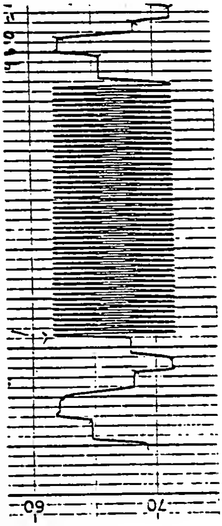
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

Date:Jul 12,1994 Sample ID:AC105P GTM Model:8A/6B/4C Binder Content(Optimum) : 5%
Mold Dia:4inches Type of Roller:Oil Filled Roller
Compaction Pres 120 psi Machine Angle(To)=1.25 degree
Total Weight of Mixture: 1256.2g Weight of Sample : 1249.9g
Height at 30 Revolutions= 2.666"
Height at 60 Revolutions= 2.558"
Initial Theta= 1.04
Minimum Theta= 0.89
Maximum Theta= 1

Number of Revolution	Mold Chuck Temp (F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	EG (psi)	GSI
		16	16	16	16	16								
50	144	2.57	2.57	2.569	2.569	2.570	148.2	1.35	11.67	1.35	51.5	2340.7	6320	1.05
		15	15	16	15	15.3								
100	140	2.494	2.491	2.491	2.491	2.492	152.6	1.32	11.51	1.32	50.6	2300.6	6212	1.05
		15	15	15	13	14.5								
150	139	2.455	2.454	2.453	2.452	2.454	155.2	1.28	11.34	1.28	48.9	2221.6	5998	1.10
		14	15	12	10	12.75								
200	139	2.434	2.432	2.431	2.431	2.432	156.5	1.13	11.24	1.13	43.4	1970.7	5321	1.12
		12	13	9	10	11								
250	139	2.419	2.416	2.416	2.417	2.416	157.5	0.98	11.17	0.98	37.6	1710.1	4617	1.16
300	-													



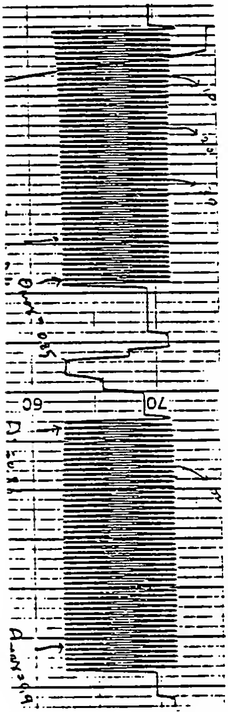
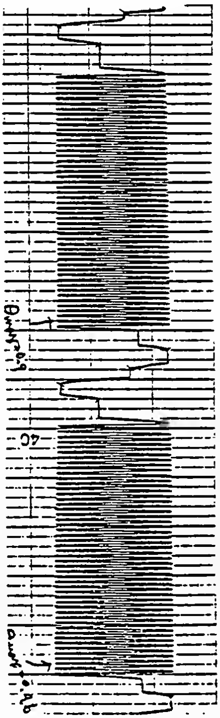
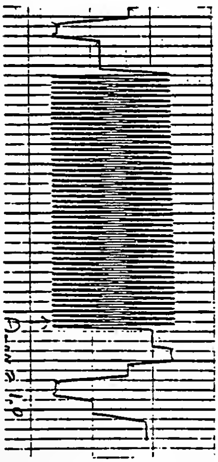




GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

Date:July 12, 199 Sample ID: AC10(10P) GTM Model:8A/6B/4C Binder Content(Optimum) : 5.1%
Mold Dia:4inches Type of Roller:Oil Filled Roller
Compaction Pres 120 psi Machine Angle(To)=1.25 degree
Total Weight of Mixture: 1256.3g Weight of Sample : 1250.8g
Height at 30 Revolutions= 2.668"
Height at 60 Revolutions= 2.557"
Initial Theta= 0.99
Minimum Theta= 0.88
Maximum Theta= 0.995

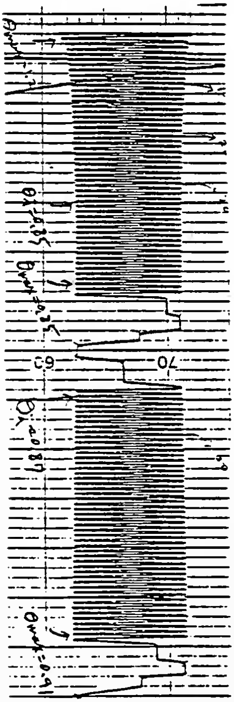
Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		15	15	16	18	16.0								
50	145	2.568	2.568	2.568	2.567	2.568	148.2	1.35	11.86	1.35	51.5	2342.3	6324	1.01
		13	16	17	16	15.5								
100	142	2.5	2.5	2.5	2.499	2.500	152.3	1.34	11.55	1.34	51.3	2330.9	6293	1.07
		14	17	15	15	15.3								
150	139	2.454	2.462	2.461	2.46	2.462	154.6	1.34	11.38	1.34	51.2	2328.7	6287	1.07
		12	16	13	13	13.5								
200	139	2.442	2.44	2.44	2.44	2.441	156.0	1.20	11.28	1.20	45.7	2079.4	5614	1.14
		12	14	11	12	12.3								
250	139	2.428	2.427	2.427	2.426	2.427	156.8	1.09	11.21	1.09	41.7	1897.4	5123	1.19
300														

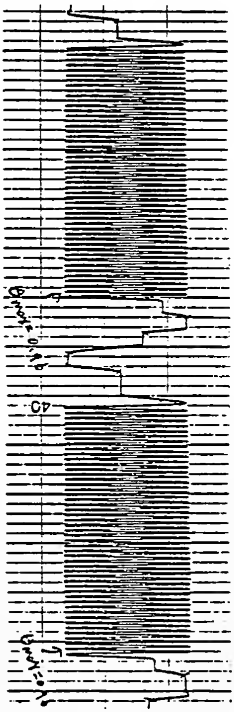




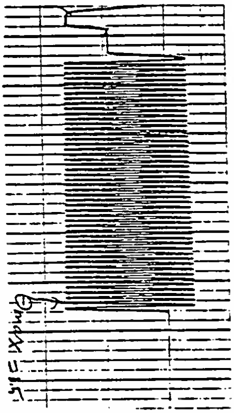
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

Date:July 12, 199 Sample ID: AC10(15P) GTM Model:8A/6B/4C Binder Content(Optimum) : 5.4%
Mold Dia:4inches Type of Roller:Oil Filled Roller
Compaction Pres 120 psi Machine Angle(To)=1.25 degree
Total Weight of Mixsture: 1263.4g Weight of Sample: 1258.2g
Height at 30 Revolutions= 2.679"
Height at 60 Revolutions= 2.567"
Initial Theta= 1.05
Minimum Theta= 0.87
Maximum Theta= 1.05

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		17	17	16	17	16.8								
50	144	2.58	2.578	2.578	2.578	2.579	147.6	1.41	11.91	1.41	53.7	2441.9	6593	1.00
		14	16	17	15	15.5								
100	142	2.51	2.508	2.508	2.507	2.508	151.8	1.34	11.59	1.34	51.1	2323.0	6272	1.07
		12	16	16	10	14.0								
150	140	2 475	2 474	2 473	2 472	2.474	153.9	1.23	11 43	1.22	46.6	2127.6	5745	1.13
		9	15	15	9	12.0								
200	139	2 455	2 452	2 451	2 45	2.452	155.2	1.06	11.33	1.06	40.5	1839.7	4967	1.13
		6	12	11	5	8.5								
250	139	2 44	2 439	2.438	2 438	2.439	156.1	0.75	11.27	0.75	28.6	1310.2	3538	1.78
300														



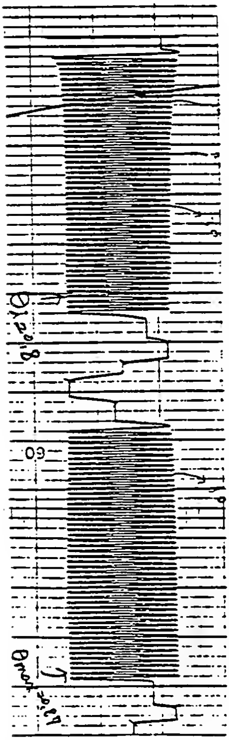


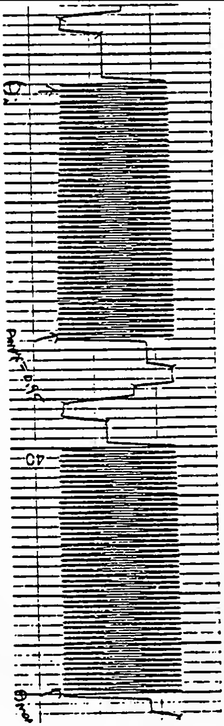


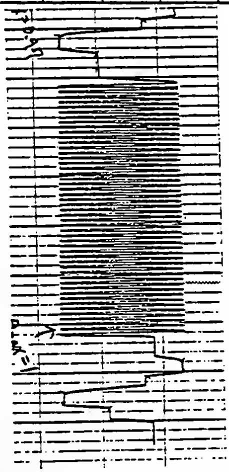
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

Date:July 12 1994 Sample ID: AC10(20P) GTM Model:8A/6B/4C Binder Content(Optimum) : 5.7%
Mold Dia:4inches Type of Roller:Oil Filled Roller
Compaction Pres 120 psi Machine Angle(To)=1.25 degree
Total Weight of Mixsture: 1266.7g Weight of Sample: 1261.9g
Height at 30 Revolutions= 2.695"
Height at 60 Revolutions= 2.595"
Initial Theta= 1
Minimum Theta= 0.8
Maximum Theta= 1

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		16	16	15	15	15.5								
50	146	2.605	2.604	2.603	2.602	2.604	147.4	1.29	12.03	1.29	49.2	2238.0	6043	1.00
		16	15	15	15	15.3								
100	143	2.538	2.537	2.536	2.535	2.537	151.3	1.30	11.72	1.30	49.7	2260.0	. 6102	1.09
		13	16	13	15	14.3								
150	140	2.5	2.5	2.5	2.5	2.500	153.5	1.23	11.55	1.23	47.1	2142.7	5785	1.19
		14	15	13	14	14.0								
200	138	2 497	2.478	2.478	2 478	2.483	154.6	1.22	11 47	1.22	46.6	2119.7	5723	1.21
		13	12	12	12	12.3								
250	139	2 463	2.461	2.46	2.46	2.461	158.0	1.08	11.37	1.08	41.2	1671.1	5052	1.25
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 **Sample ID: AC10(5CB)** **Binder Content(Optimum) : 5.0%**

Mold Dia:4inches **Type of Roller: Oil Filled Roller**

Compaction Pressure= 120psi **Machine Angle(To)=1.25 degree**

Total Weight of Mixture: 1247.3g **Weight of Sample:1241.2g**

Height at 30 Revolutions=2.68"

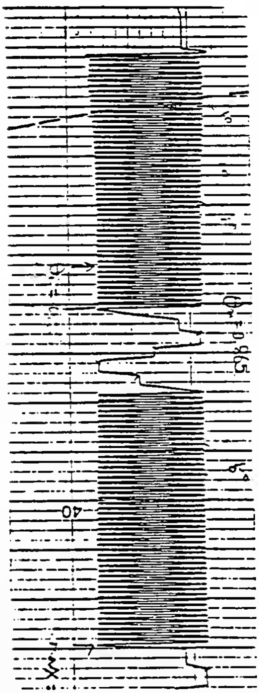
Height at 60 Revolutions=2.548"

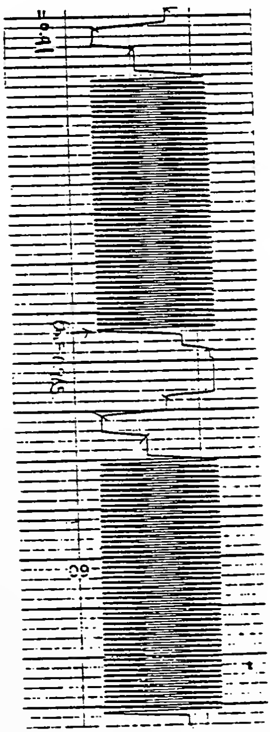
Initial Theta=1.000

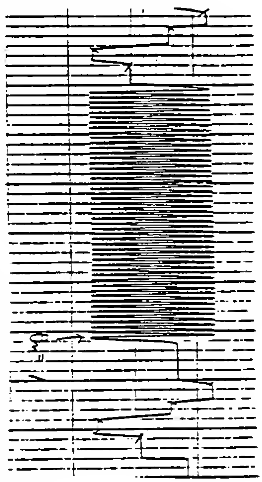
Minimum Theta=0.873

Maximum Theta=0.999

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		13	16	13	12	13.5								
50	145	2.52	2.5	2.549	2 549	2.530	149.4	1.16	11.69	1.18	44 1	2006.2	5417	1.00
		9	16	15	9	12.3								
100	143	2 482	2.481	2 48	2 48	2 481	152.3	1.07	11 45	1.07	40.6	1856.2	5012	1.06
		7	15	13	6	10.3								
150	140	2 449	2 447	2 445	2 445	2 447	154.5	0.91	11.30	0.91	34.6	1574.9	4252	1.13
		13	15	10	5	10 8								
200	139	2 425	2 425	2 422	2.422	2 424	155.9	0.96	11.20	0.96	36.7	1667.4	4502	1.14
		13	12	9	2	9.0								
250	139	2 408	2 408	2.408	2.408	2.408	156.9	0.81	11.13	0.81	30.9	1405.0	3793	1.16
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 Sample ID: AC10(10CB) Binder Content(Optimum) : 5.2%

Mold Dia:4inches Type of Roller: Oil Filled Roller

Compaction Pressure= 120psi Machine Angle(To)=1.25 degree

Total Weight of Mixture: 1256.2g Weight of Sample:1248.4g

Height at 30 Revolutions=2.688"

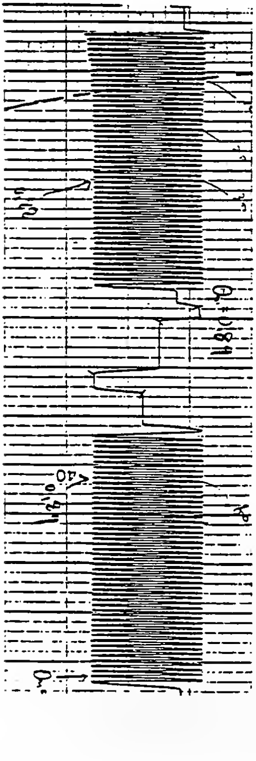
Height at 60 Revolutions=2.565"

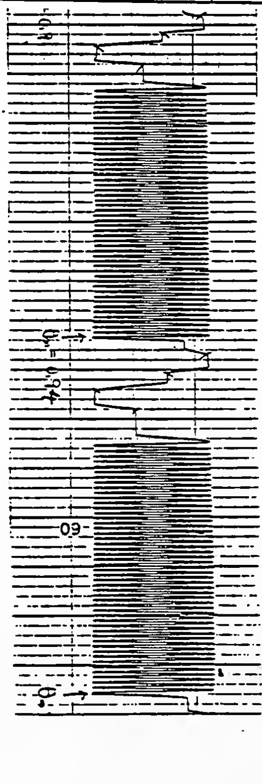
Initial Theta=1.018

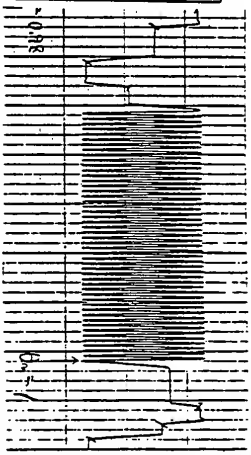
Minimum Theta=0.878

Maximum Theta=1.000

Number of Revolution	Mold Chuck Temp (F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
50	145	15	19	16	15	16.3	147.9	1.57	11.89	1.37	52.2	2372.9	6407	1.01
		2.58	2.575	2.571	2.571	2.574								
100	142	15	15	16	14	15.0	152.3	1.30	11.55	1.30	49.6	2255.5	6090	1.02
		2.501	2.5	2.5	2.499	2.500								
150	140	13	16	16	13	14.5	154.6	1.28	11.37	1.27	48.7	2214.6	5979	1.07
		2.465	2.46	2.48	2.46	2.461								
200	139	11	15	13	10	12.3	156.0	1.09	11.28	1.09	41.5	1887.1	5085	1.11
		2.441	2.44	2.44	2.44	2.440								
250	139	12	15	11	6	11.5	157.0	1.03	11.21	1.03	39.2	1782.7	4813	1.14
		2.425	2.425	2.425	2.425	2.425								
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 | Sample ID: AC10(15CB) | Binder Content(Optimum) : 5.3%

Mold Dia:4inches | Type of Roller: Oil Filled Roller

Compaction Pressure= 120psi | Machine Angle(To)=1.25 degree

Total Weight of Mixsture: 1257.2g | Weight of Sample:1251.0g

Height at 30 Revolutions=2.66"

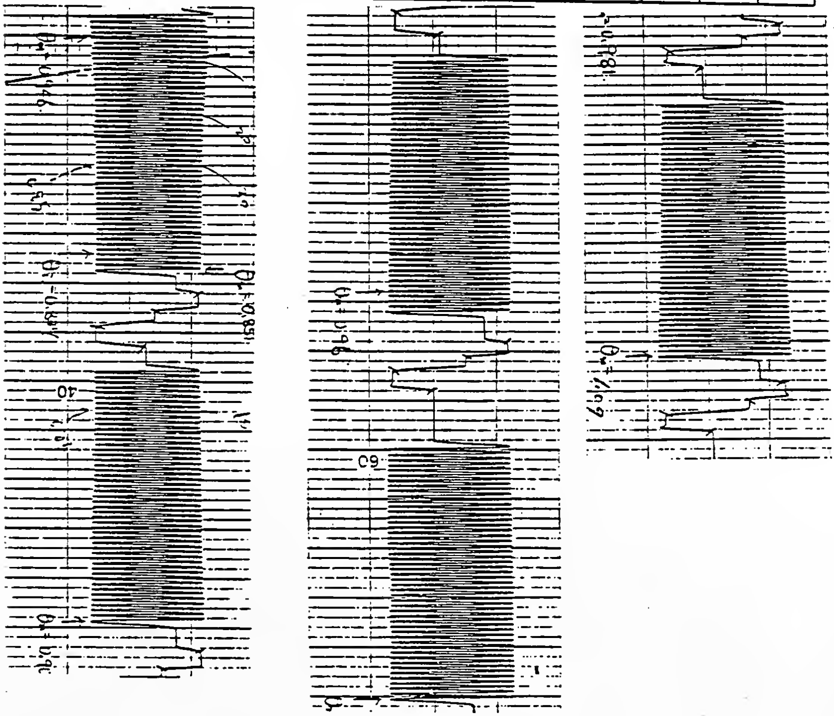
Height at 60 Revolutions=2.54"

Initial Theta=1.021

Minimum Theta=0.833

Maximum Theta=1.097

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
50	145	17	18	18	17	17.5	149.3	1.48	11.79	1.48	56.7	2578.0	6961	1.01
		2.557	2.55	2.55	2.55	2.552								
100	143	15	16	16	17	16.0	153.6	1.40	11.48	1.40	53.3	2425.0	6547	1.06
		2 481	2 48	2 48	2 48	2 480								
150	140	11	16	16	12	13.6	155.6	1.22	11.31	1.22	46 4	2111.2	5700	1.01
		2 449	2 448	2 448	2 448	2 448								
200	139	6	14	10	8	10.0	156.8	0.89	11.23	0.89	34.0	1547.3	4178	1.15
		2 43	2.43	2 429	2 429	2 430								
250	139	5	6	6	3	5 0	157.4	0 45	11.18	0 45	17.1	778 6	2097	1.28
		2.421	-2 42	2 42	2.42	2 420								
300														



GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 Sample ID: AC10(20CB) Binder Content(Optimum) : 5.6%

Mold Dia:4inches Type of Roller: Oil Filled Roller

Compaction Pressure= 120psi Machine Angle(To)=1.25 degree

Total Weight of Mixature: 1261.5g Weight of Sample:1254.1g

Height at 30 Revolutions=2.63"

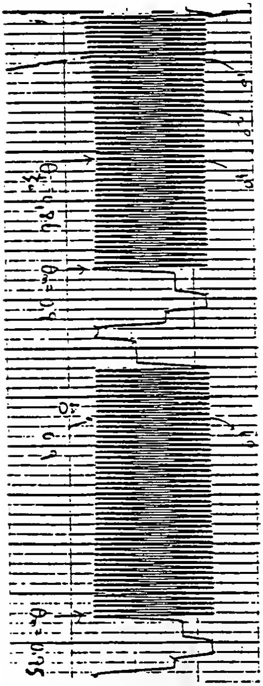
Height at 60 Revolutions=2.516"

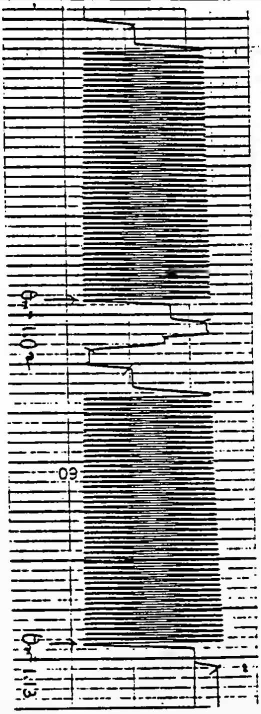
Initial Theta=1.501

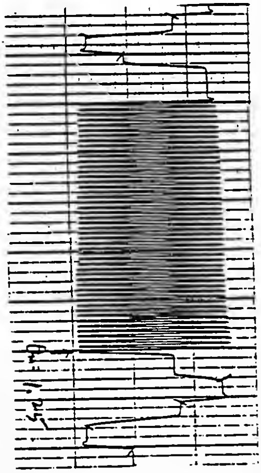
Minimum Theta=0.859

Maximum Theta=1.251

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		16	18	18	10	15.0								
50	145	2.534	2.529	2.528	2.528	2.530	151.1	1.28	11.69	1.28	49.0	2228.9	6016	1.05
		12	16	18	15	15.3								
100	143	2.465	2.46	2.46	2.46	2.461	155.3	1.34	11.37	1.34	51.2	2329.1	6289	1.10
		6	13	13	8	10.0								
150	140	2.439	2.437	2.435	2.435	2.437	156.9	0.89	11.28	0.89	33.9	1542.6	4166	1.19
		0	7	8	4	4.8								
200	139	2.428	2.425	2.425	2.425	2.426	157.8	0.42	11.21	0.42	18.2	736.1	1987	1.31
		0	3	4	1	2.0								
250	139	2.42	2.42	2.418	2.418	2.420	158.0	0.18	11.18	0.18	8.8	310.7	839	1.45
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 13, 1994 Sample I.D. : AC20 Binder Content(Optimum) : 4.2%

Mold Dia:4inches Type of Roller: Oil Filled Roller

Compaction Pressure= 120psi Machine Angle(To)=1.25 degree

Total Weight of Mixture: 1237.2g Weight of Sample:1234.1g

Height at 30 Revolutions=2.655"

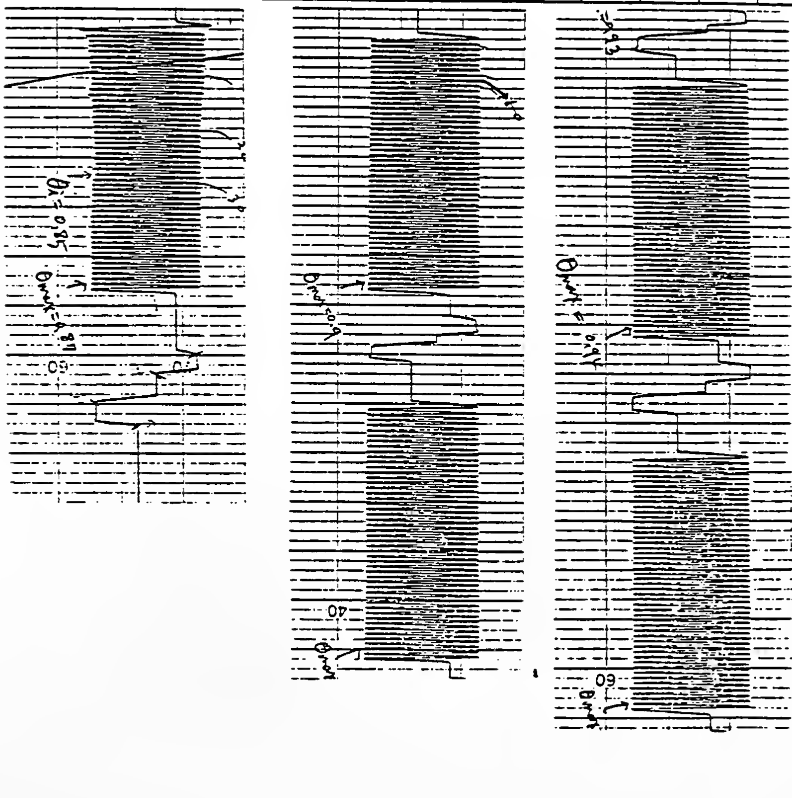
Height at 60 Revolutions=2.498"

Initial Theta=1.070

Minimum Theta=0.862

Maximum Theta=0.969

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		13	16	14	7	12.5								
50	144	2.559	2.559	2.558	2.558	2.559	146.5	1.06	11.82	1.06	40.4	1836.6	4959	1.02
		12	16	15	6	12.3								
100	142	2.49	2.49	2.49	2.49	2.490	150.6	1.07	11.51	1.06	40.7	1849.4	4993	1.06
		7	13	15	7	10.5								
150	139	2.464	2.464	2.463	2.462	2.463	152.2	0.92	11.38	0.92	35.3	1602.4	4326	1.09
		12	15	16	6	12.3								
200	139	2.43	2.429	2.426	2.428	2.429	154.3	1.09	11.22	1.09	41.7	1898.0	5119	1.11
		14	14	14	7	12.3								
250	139	2.41	2.41	2.409	2.41	2.410	155.6	1.10	11.13	1.10	42.0	1910.9	5160	1.12
300														



GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date:Jul 13,1994 **Sample ID: AC20(5P)** **Binder Content(Optimum) : 4.7%**

Mold Dia:4inches **Type of Roller: Oil Filled Roller**

Compaction Pressure= 120psi **Machine Angle(To)=1.25 degree**

Total Weight of Mixture: 1249.9g **Weight of Sample:1244.9g**

Height at 30 Revolutions=2.657"

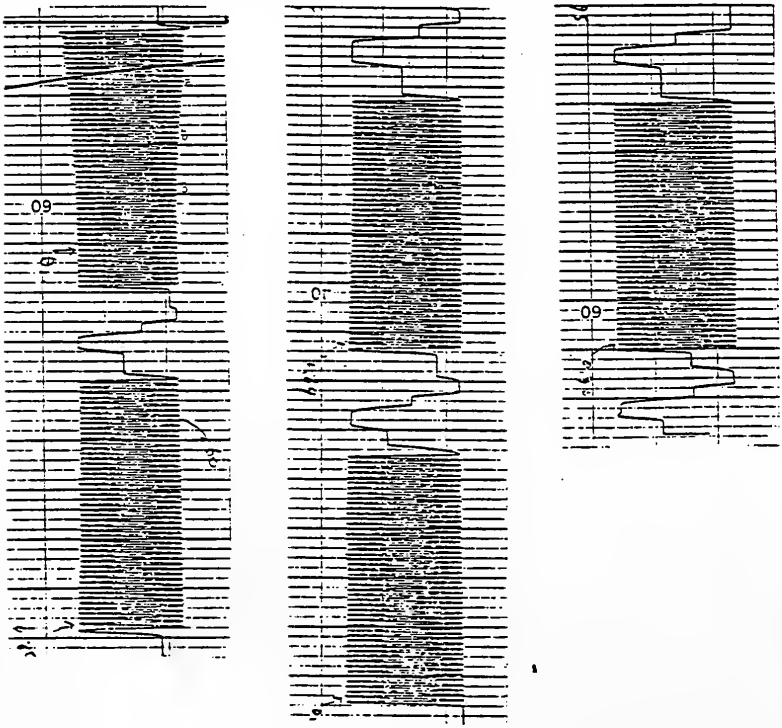
Height at 60 Revolutions=2.554"

Initial Theta=1.048

Minimum Theta=0.805

Maximum Theta=0.958

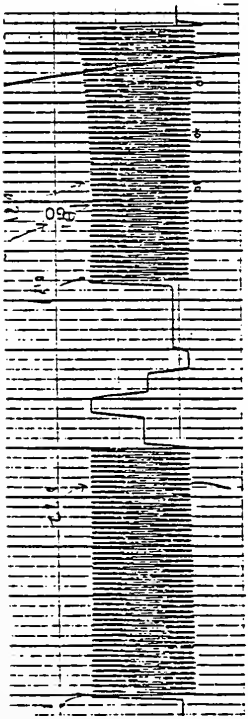
Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		11	19	18	15	15.6								
50	148	2.566	2.63	2.562	2.562	2.580	148.6	1.32	11.92	1.32	50.5	2294.6	6196	0.98
		17	17	18	14	16.0								
100	143	2.493	2.493	2.493	2.492	2.493	151.9	1.39	11.52	1.39	53.1	2412.6	6515	1.04
		10	15	16	16	14.3								
150	141	2.458	2.458	2.458	2.458	2.458	154.1	1.26	11.36	1.25	47.9	2179.3	5884	1.09
		13	12	12	12	12.3								
200	139	2.437	2.437	2.437	2.436	2.437	155.4	1.09	11.26	1.09	41.6	1889.8	5102	1.16
		12	13	13	10	12.0								
250	139	2.423	2.422	2.421	2.421	2.422	156.4	1.07	11.19	1.07	41.0	1862.7	5029	1.17
300														

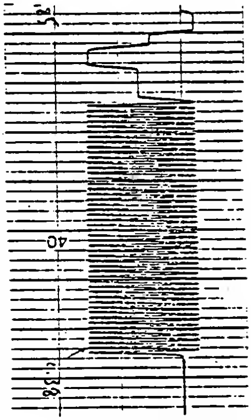


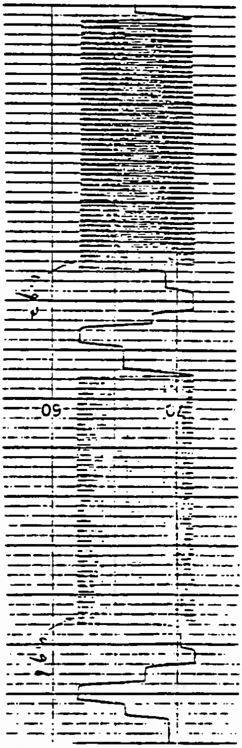
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C
Date: Jul 13, 1994 Sample ID: AC20(10P) Binder Content(Optimum) : 4.8%
Mold Die:4inches Type of Roller: Oil Filled Roller
Compaction Pressure= 120psi Machine Angle(To)=1.25 degree
Total Weight of Mixture: 1255.7g Weight of Sample:1251.9g
Height at 30 Revolutions=2.674"
Height at 60 Revolutions=2.579"
Initial Theta=1.040
Minimum Theta=0.799
Maximum Theta=0.961

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		16	15	14	15	15.0								
50	145	2.59	2.59	2.59	2.589	2.590	148.9	1.25	11.97	1.25	47.9	2177.3	5879	1.01
		14	16	16	16	16.0								
100	142	2.524	2.524	2.523	2.523	2.524	150.8	1.37	11.66	1.37	52.4	2383.4	6435	1.06
		14	16	15	14	15.3								
150	139	2.485	2.485	2.484	2.484	2.485	153.1	1.33	11.48	1.33	50.8	2307.4	6230	1.10
		14	16	15	13	14.5								
200	139	2.462	2.461	2.46	2.46	2.461	154.6	1.28	11.37	1.28	48.7	2215.0	5981	1.15
		13	13	12	15	13.3								
250	139	2.446	2.444	2.444	2.444	2.445	155.6	1.17	11.30	1.17	44.8	2037.6	5501	1.20
300														



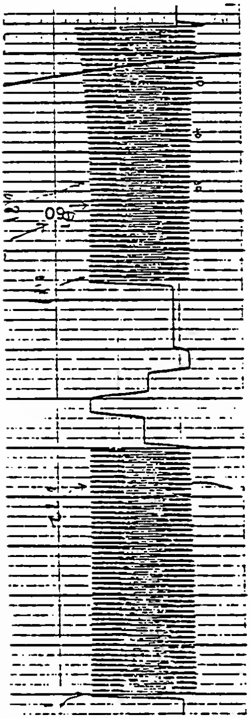


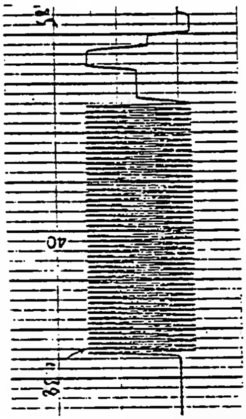


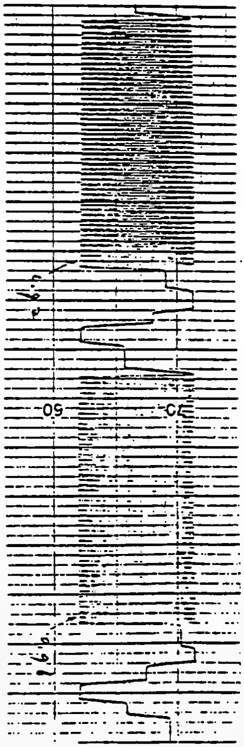
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C
Date: Jul 13, 1994 | **Sample ID: AC20(10P)** | **Binder Content(Optimum) : 4.8%**
Mold Dia:4inches | **Type of Roller: Oil Filled Roller**
Compaction Pressure= 120psi | **Machine Angle(To)=1.25 degree**
Total Weight of Mixature: 1255.7g | **Weight of Sample:1251.9g**
Height at 30 Revolutions=2.674"
Height at 60 Revolutions=2.579"
Initial Theta=1.040
Minimum Theta=0.799
Maximum Theta=0.961

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		16	15	14	15	15.0								
50	145	2.59	2.59	2.59	2.589	2.590	146.9	1.25	11.97	1.25	47.9	2177.3	5879	1.01
		14	16	18	16	16.0								
100	142	2.524	2.524	2.523	2.523	2.524	150.6	1.37	11.68	1.37	52.4	2383.4	6435	1.06
		14	18	15	14	15.3								
150	139	2.485	2.485	2.484	2.484	2.485	153.1	1.33	11.48	1.33	50.6	2307.4	6230	1.10
		14	16	15	13	14.5								
200	139	2.462	2.461	2.46	2.46	2.461	154.6	1.28	11.37	1.28	48.7	2215.0	5961	1.15
		13	13	12	15	13.3								
250	139	2.446	2.444	2.444	2.444	2.445	155.6	1.17	11.30	1.17	44.6	2037.6	5501	1.20
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 13, 1994 **Sample ID: AC20(15P)** **Binder Content(Optimum) : 5.2%**

Mold Dia:4inches **Type of Roller: Oil Filled Roller**

Compaction Pressure= 120psi **Machine Angle(To)=1.25 degree**

Total Weight of Mixture: 1258.3g **Weight of Sample:1253.9g**

Height at 30 Revolutions=2.668"

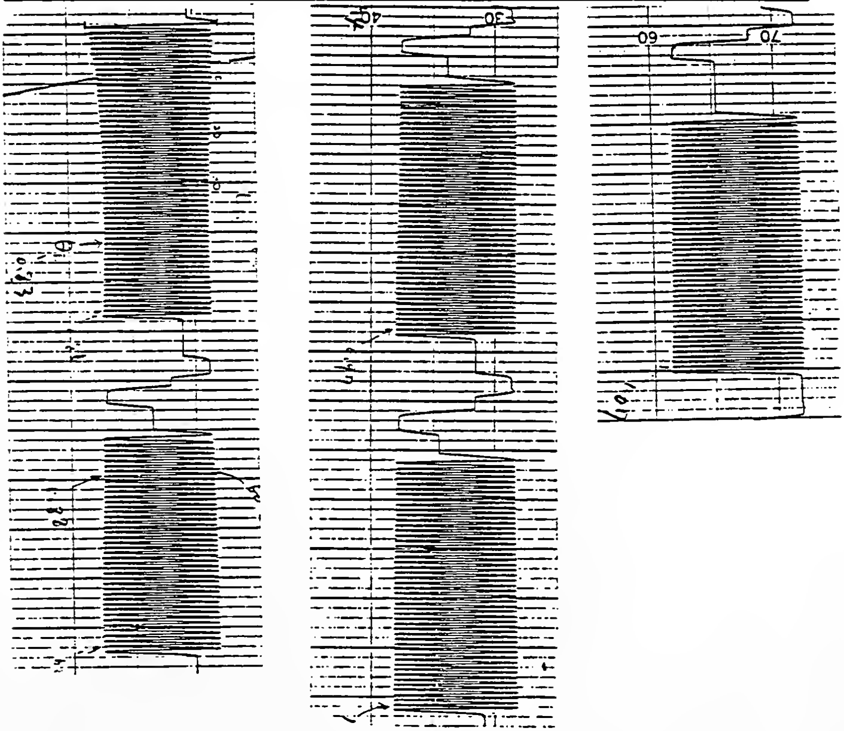
Height at 60 Revolutions=2.561"

Initial Theta=1.053

Minimum Theta=0.828

Maximum Theta=1.071

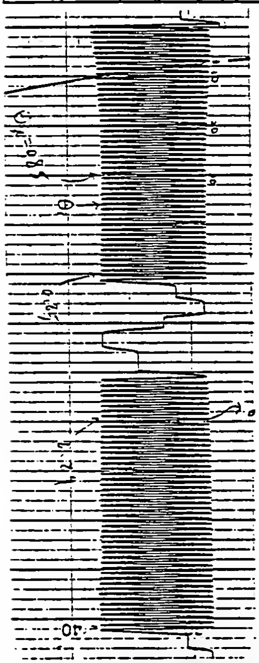
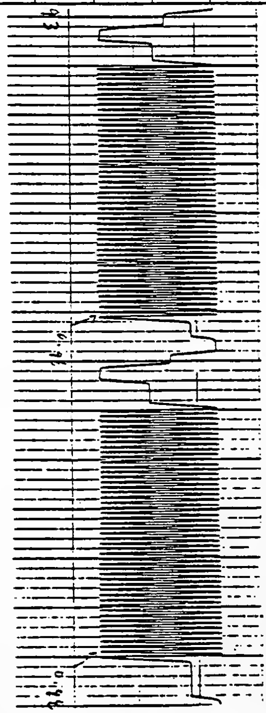
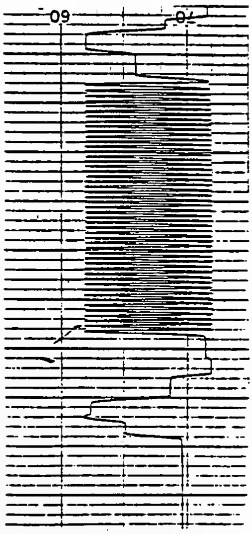
Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		14	19	16	18	16.8								
50	144	2.568	2.568	2.568	2.568	2.568	148.5	1.41	11.87	1.41	53.9	2451.9	6620	1.04
		10	15	15	16	14.0								
100	141	2.514	2.512	2.512	2.512	2.513	151.7	1.21	11.81	1.21	48.1	2094.6	5655	1.13
		12	14	13	15	13.5								
150	140	2.479	2.478	2.478	2.478	2.478	153.8	1.18	11.45	1.18	45.0	2047.7	5529	1.17
		10	14	11	15	12.5								
200	139	2.459	2.457	2.457	2.456	2.457	155.2	1.10	11.35	1.10	42.1	1912.2	5163	1.20
		8	13	11	12	11.0								
250	139	2.444	2.443	2.443	2.442	2.443	156.1	0.97	11.29	0.97	37.2	1692.6	4570	1.29
300														



GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C
Date: Jul 13, 1994 **Sample ID: AC20(20P)** **Binder Content(Optimum) : 5.5%**
Mold Dia:4inches **Type of Roller: Oil Filled Roller**
Compaction Pressure= 120psi **Machine Angle(To)=1.25 degree**
Total Weight of Mixture: 1262.9g **Weight of Sample:1258.5g**
Height at 30 Revolutions=2.682"
Height at 60 Revolutions=2.580"
Initial Theta=1.052
Minimum Theta=0.845
Maximum Theta=1.008

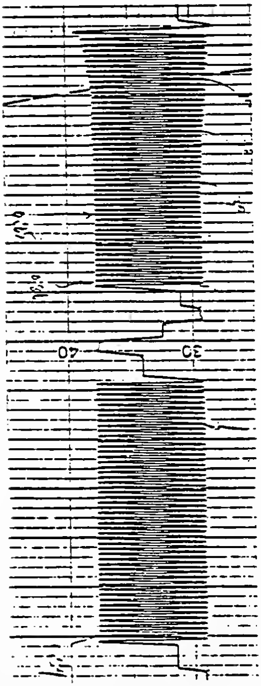
Number of Revolution	Mold Chuck Temp (F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		13	16	16	15	15.0								
50	147	2.592	2.589	2.589	2.587	2.589	147.6	1.25	11.96	1.25	47.9	2177.7	5880	1.00
		6	16	15	15	13.5								
100	144	2.528	2.526	2.525	2.524	2.526	151.5	1.16	11.67	1.16	44.2	2009.2	5425	1.09
		15	13	15	14	14.3								
150	141	2.493	2.49	2.49	2.49	2.491	153.6	1.24	11.51	1.24	47.3	2150.6	5807	1.13
		16	13	9	11	12.3								
200	139	2.47	2.47	2.47	2.47	2.470	154.9	1.07	11.41	1.07	41.0	1864.3	5034	1.15
		10	12	7	9	9.5								
250	139	2.46	2.457	2.457	2.457	2.456	155.7	0.84	11.36	0.84	32.0	1453.0	3923	1.16
300														

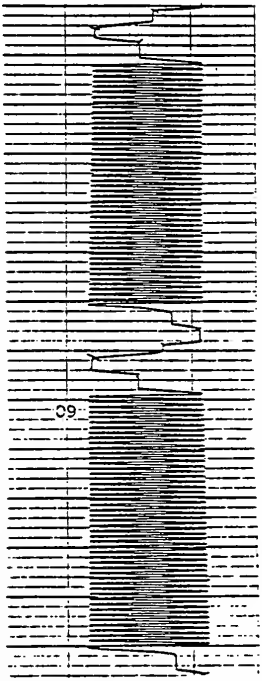




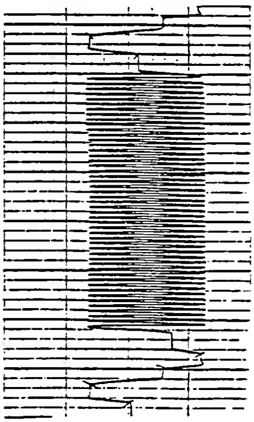
GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C
Date: Jul 14, 1994 Sample ID: AC20(5C) Binder Content(Optimum):4.7%
Mold Die:4inches Type of Roller: Oil Filled Roller
Compaction Pressure= 120psi Machine Angle(To)=1.25 degree
Total Weight of Mixture: 1238.6g Weight of Sample:1233.4g
Height at 30 Revolutions=2.66"
Height at 60 Revolutions=2.54"
Initial Theta=1.116
Minimum Theta=0.861
Maximum Theta=0.983

Number of Revolution	Mold Chuck Temp (F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		10	15	16	9	12.5								
50	146	2.56	2.555	2.555	2.554	2.556	146.8	1.06	11.81	1.06	40.4	1838.4	4964	1.00
		9	16	15	9	12.3								
100	143	2.485	2.482	2.482	2.482	2.483	151.2	1.07	11.47	1.07	40.8	1854.8	5008	1.03
		11	15	16	9	12.8								
150	141	2.45	2.449	2.449	2.449	2.449	153.2	1.13	11.32	1.13	43.1	1956.9	5284	1.06
		8	13	15	11	11.8								
200	139	2.427	2.426	2.425	2.424	2.426	154.7	1.05	11.21	1.05	40.1	1821.0	4917	1.10
		13	13	14	13	13.3								
250	139	2.41	2.41	2.409	2.409	2.410	155.6	1.19	11.13	1.19	45.5	2067.1	5581	1.12
300														







GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 **Sample ID: AC20(10CB)** **Binder Content(Optimum):4.9%**

Mold Dia:4inches **Type of Roller: Oil Filled Roller**

Compaction Pressure= 120psi **Machine Angle(To)=1.25 degree**

Total Weight of Mixture: 1251.0g **Weight of Sample:1233.4g**

Height at 30 Revolutions=2.646"

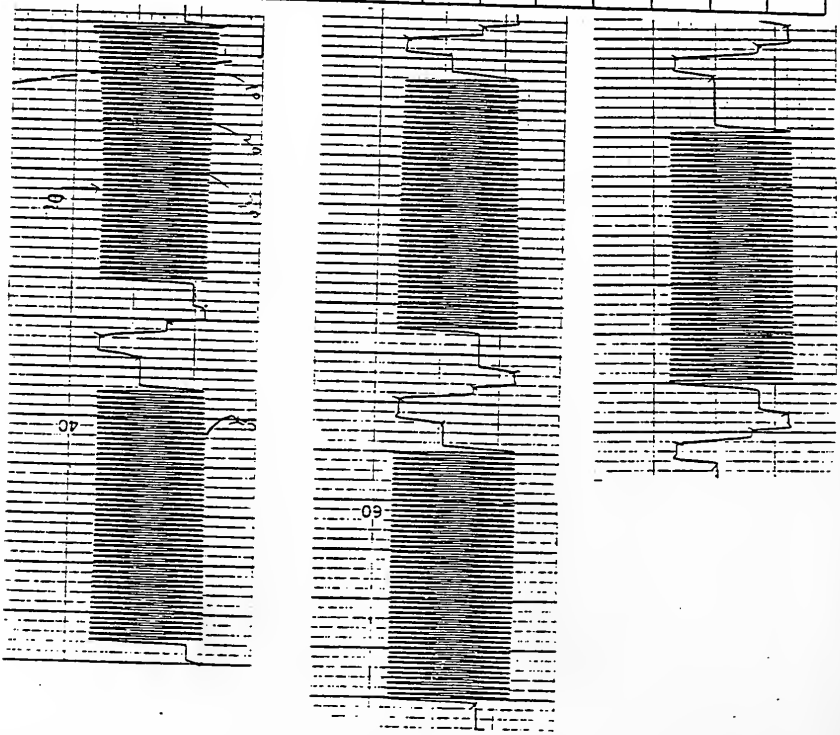
Height at 60 Revolutions=2.54"

Initial Theta=1.063

Minimum Theta=0.671

Maximum Theta=1.011

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
50	142	12	15	15	10	13.0	148.6	1.10	11.78	1.10	42.2	1918.4	5174	1.02
		2.55	2.55	2.55	2.55	2.550								
100	140	9	13	15	9	11.5	152.8	1.00	11.47	1.00	38.3	1742.2	4704	1.06
		2.485	2.48	2.48	2.48	2.481								
150	139	9	9	15	7	10.0	154.8	0.88	11.31	0.88	33.8	1535.6	4148	1.15
		2.448	2.448	2.448	2.448	2.448								
200	140	16	7	11	12	11.5	156.1	1.03	11.22	1.02	39.2	1780.1	4806	1.16
		2.43	2.428	2.428	2.428	2.429								
250	140	13	13	11	11	12.0	157.1	1.08	11.15	1.08	41.1	1869.2	5047	1.28
		2.415	2.413	2.413	2.412	2.413								
300														



GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

GTM Model: 8A/6B/4C

Date: Jul 14, 1994 Sample ID: AC20(15CB) Binder Content(Optimum):5.1%

Mold Dia:4inches Type of Roller: Oil Filled Roller

Compaction Pressure= 120psi Machine Angle(To)=1.25 degree

Total Weight of Mixture: 1254.3g Weight of Sample:1248.8g

Height at 30 Revolutions=2.635"

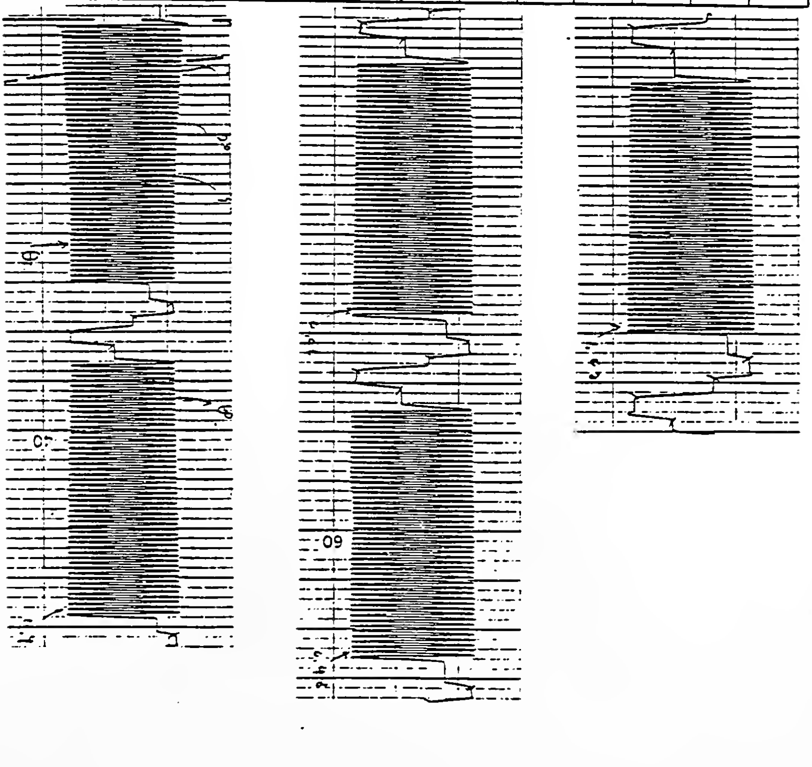
Height at 60 Revolutions=2.53"

Initial Theta=1.069

Minimum Theta=0.843

Maximum Theta=1.037

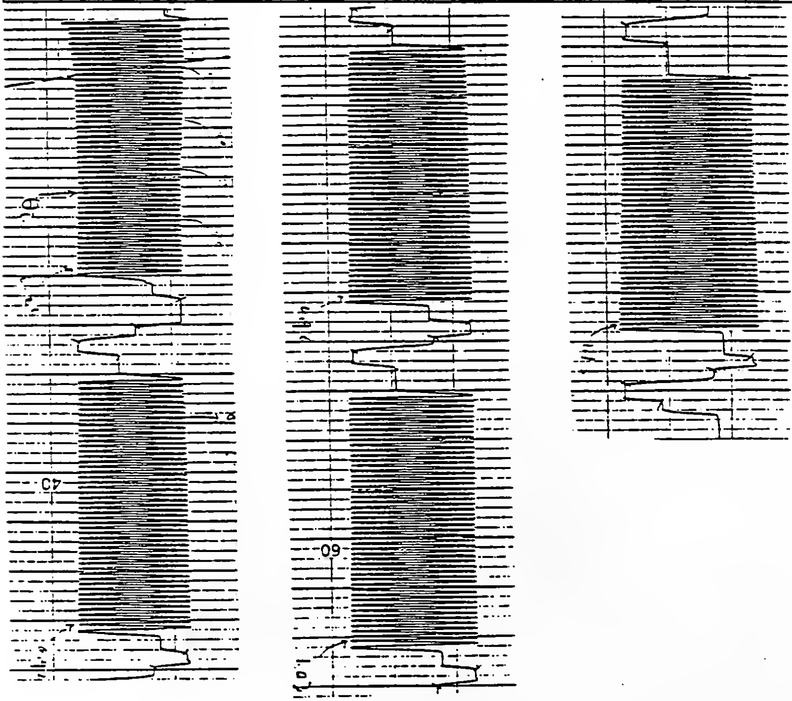
Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		1	2	3	4									
50	148	17	17	19	18	17.3	149.8	1.47	11.72	1.47	56.2	2555.9	6901.1	0.99
		2.54	2.536	2.536	2.536	2.537								
100	144	15	18	14	17	16.0	153.8	1.40	11.42	1.40	53.8	2434.5	6573.3	1.06
		2.472	2.47	2.47	2.47	2.471								
150	141	14	18	15	15	15.0	156.0	1.33	11.26	1.33	50.9	2314.5	6249.1	1.13
		2.438	2.437	2.435	2.435	2.436								
200	140	13	13	13	11	12.5	157.1	1.12	11.18	1.12	42.7	1942.9	5245.8	1.15
		2.42	2.418	2.418	2.418	2.419								
250	139	11	11	12	8	10.5	158.0	0.94	11.12	0.94	36.1	1640.7	4429.8	1.41
		2.409	2.406	2.405	2.403	2.406								
300														



GTM COMPACTION AND SHEAR TEST FOR BITUMINOUS MIXTURES

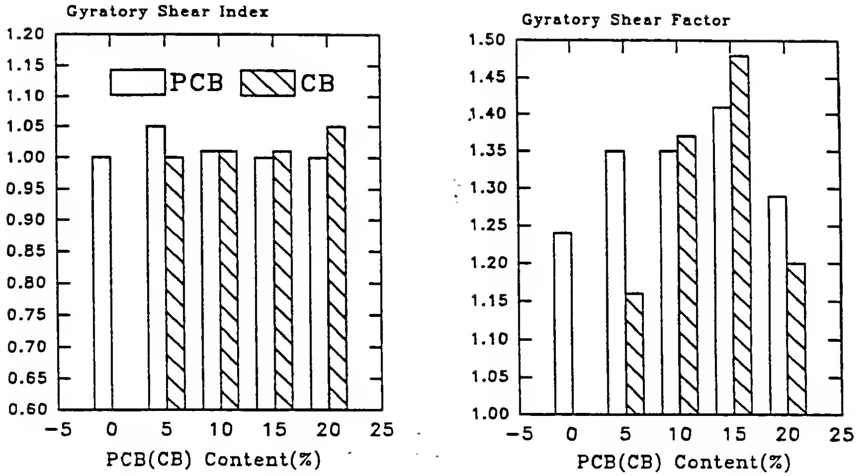
GTM Model: 8A/6B/4C
Date: Jul 14, 1994 Sample ID: AC20(20CB) Binder Content(Optimum):5.4%
Mold Dia:4inches Type of Roller: Oil Filled Roller
Compaction Pressure= 120psi Machine Angle(To)=1.25 degree
Total Weight of Mixture: 1261.0g Weight of Sample:1255.7g
Height at 30 Revolutions=2.66"
Height at 60 Revolutions=2.535"
Initial Theta=1.064
Minimum Theta=0.881
Maximum Theta=1.120

Number of Revolution	Mold Chuck Temp.(F)	Roller Pressure (psi) / Specimen Height(in.) / Roller Position(1/2/3/4)				Avg	Unit Weight (lb/ft3)	GSF	p' (psi)	p/p'	Sg (psi)	Gg (psi)	Eg (psi)	GSI
		16	17	18	13	15.5								
50	148	2.546	2.541	2.5	2.5	2.522	151.5	1.33	11.65	1.33	50.8	2310.5	6238	1.01
		14	16	18	8	14.0								
100	144	2.475	2.471	2.471	2.47	2.472	154.8	1.23	11.42	1.23	46.6	2129.2	5749	1.06
		9	14	16	5	11.0								
150	141	2.441	2.44	2.44	2.439	2.440	156.8	0.98	11.27	0.98	37.3	1694.7	4576	1.15
		6	11	12	0	7.3								
200	139	2.425	2.422	2.42	2.42	2.422	157.8	0.65	11.19	0.65	24.8	1125.4	3038	1.21
		0	7	7	3	4.3								
250	139	2.415	2.412	2.411	2.41	2.412	158.4	0.38	11.15	0.38	14.6	662.4	1788	1.33
300														

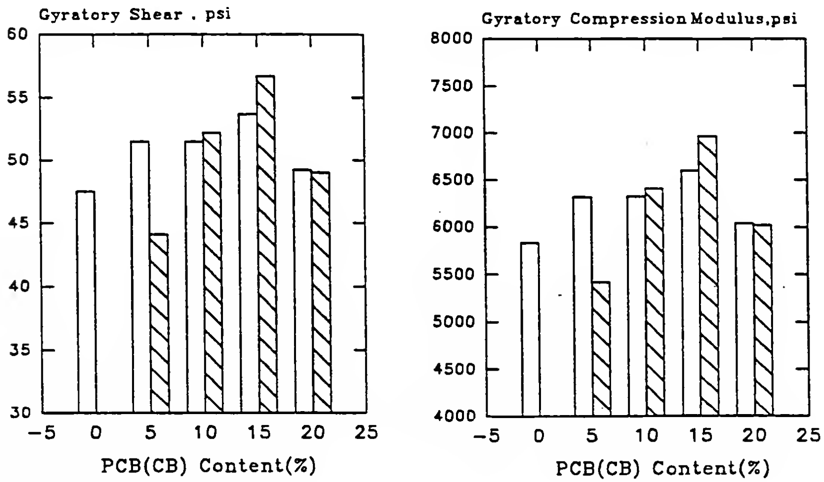


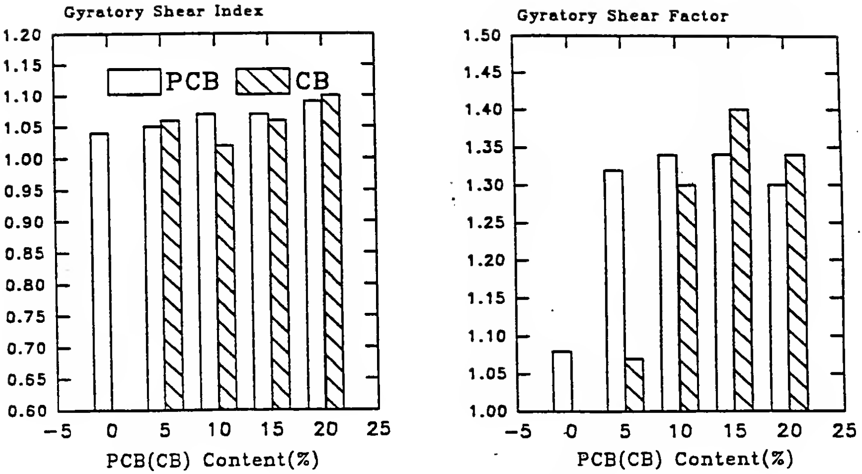
APPENDIX G

Comparison of GSF, Sg and Gg

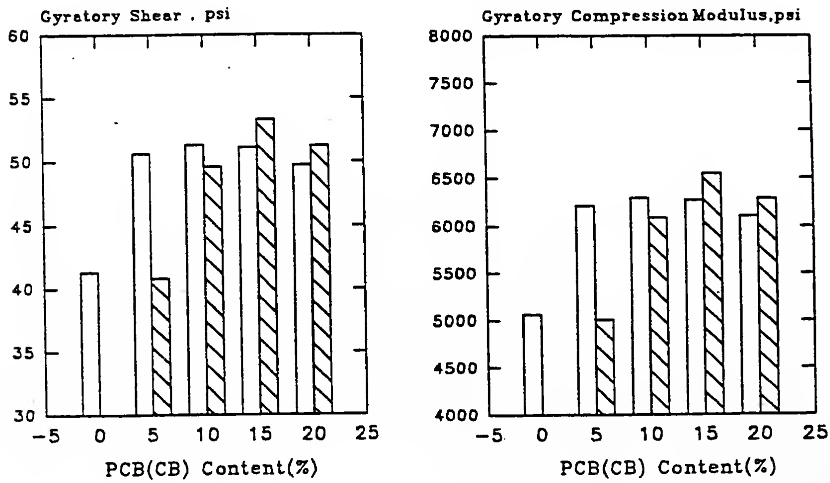


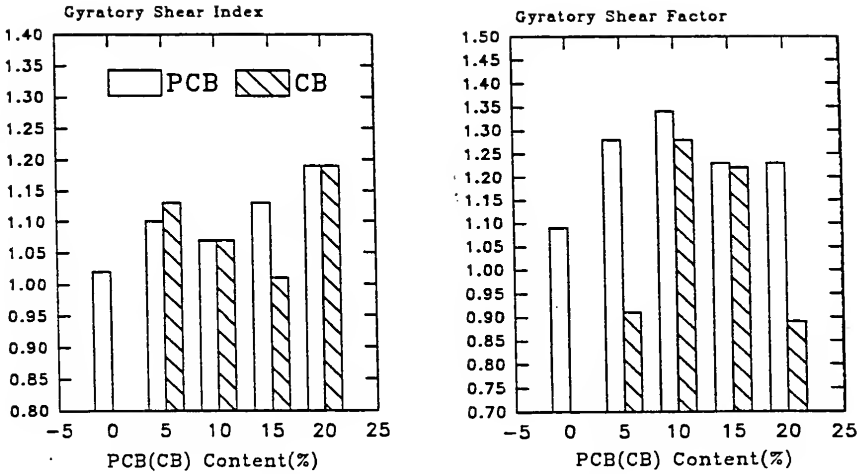
AC-10 Mixture (50 Revolutions)



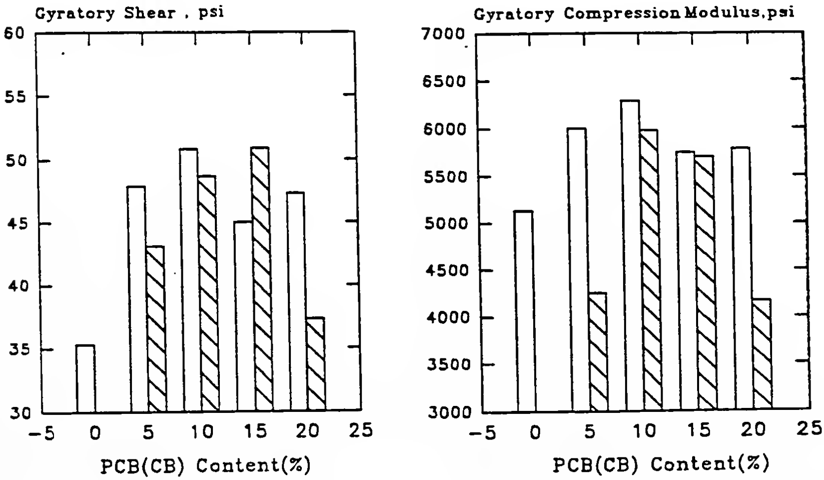


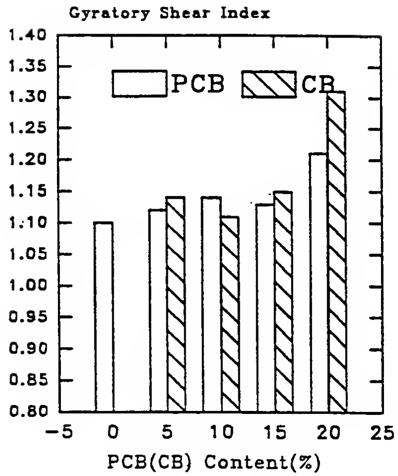
AC-10 Mixture (100 Revolutions)

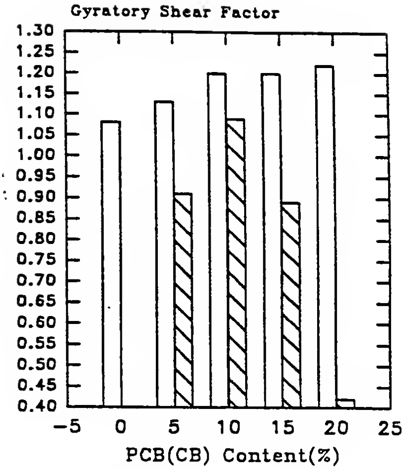




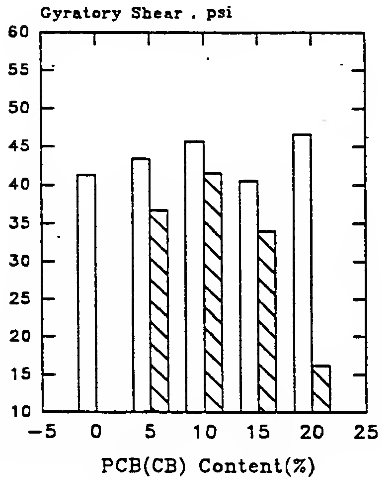
AC-10 Mixture (150 Revolutions)

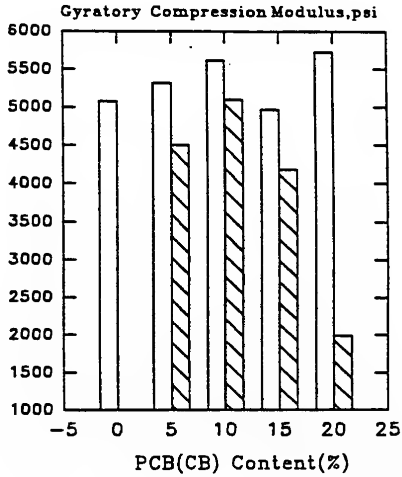


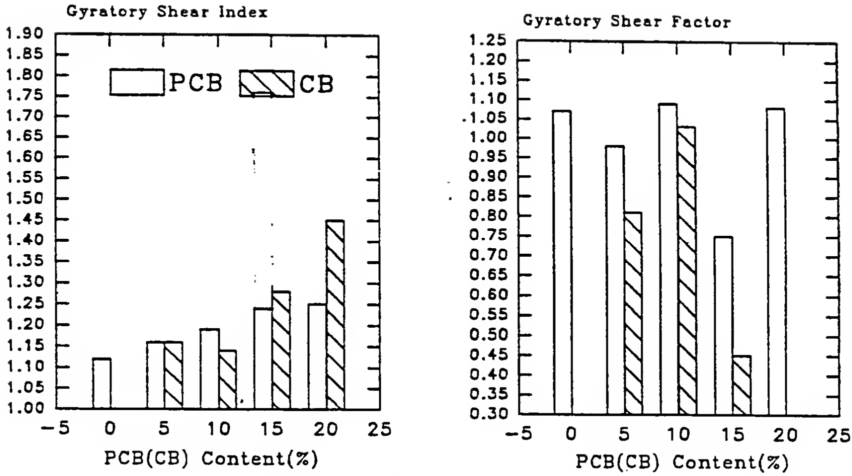




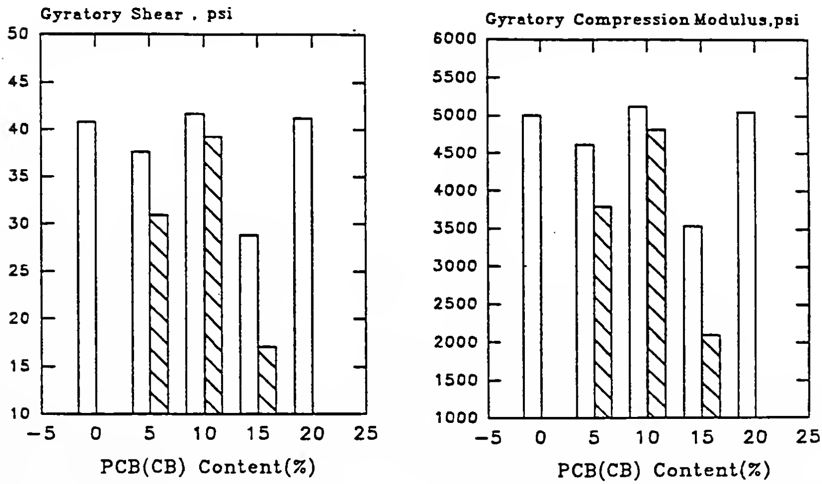
AC-10 Mixture (200 Revolutions)

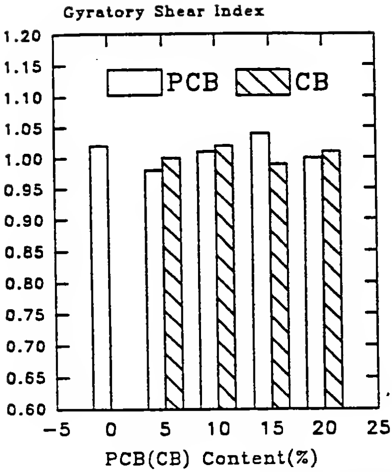


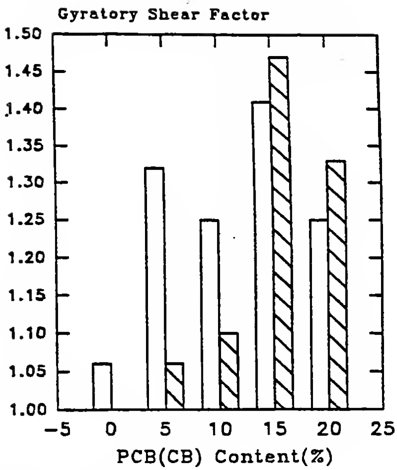




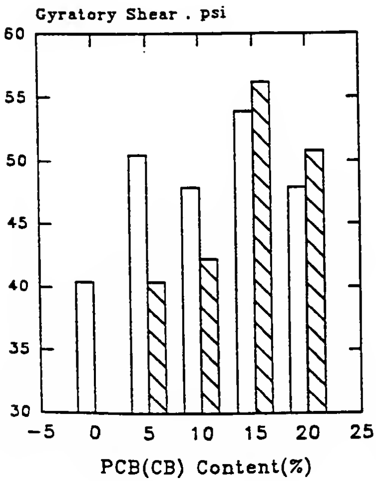
AC-10 Mixture (250 Revolutions)

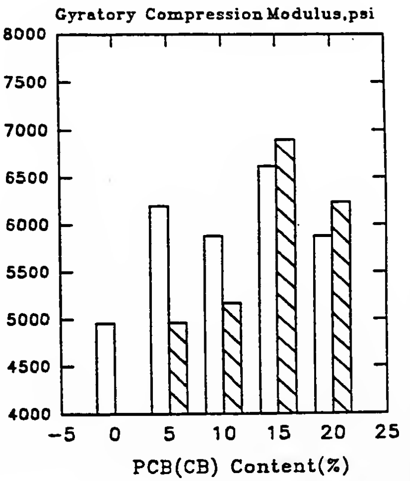


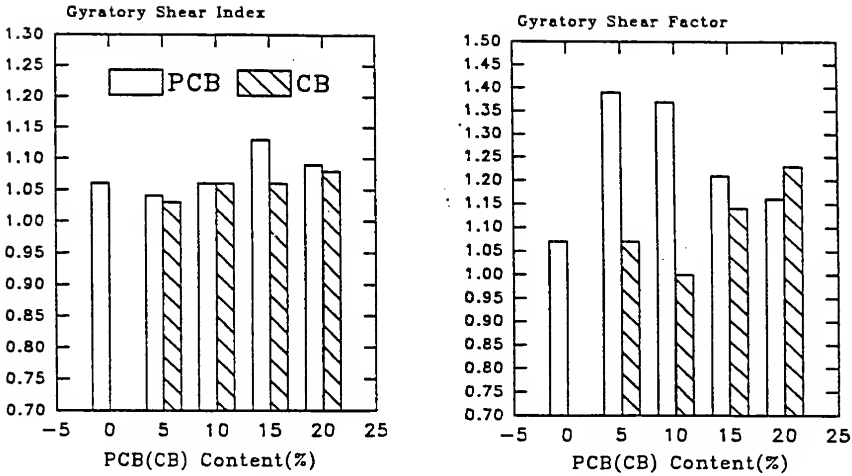




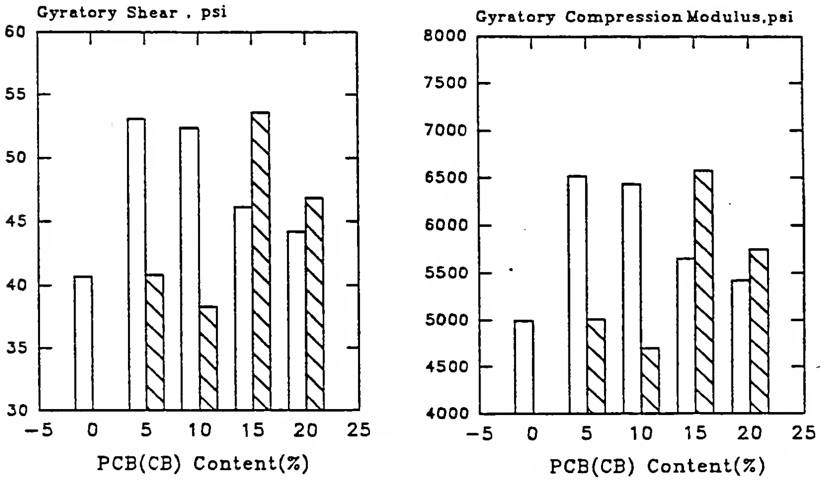
AC-20 Mixture (50 Revolutions)

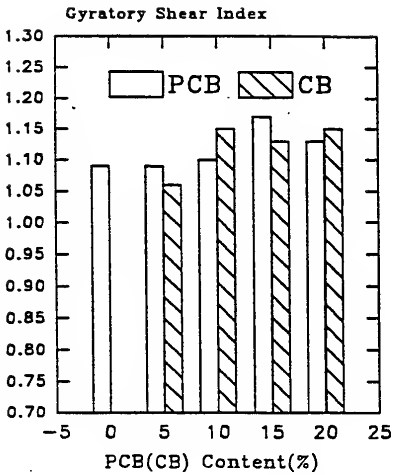


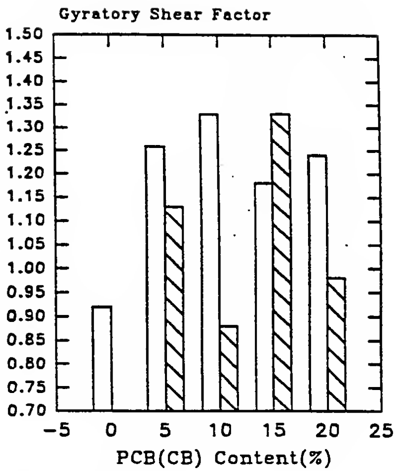




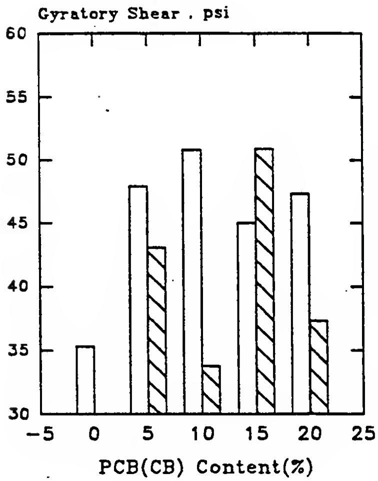
Ac-20 Mixture (100 Revolutions)

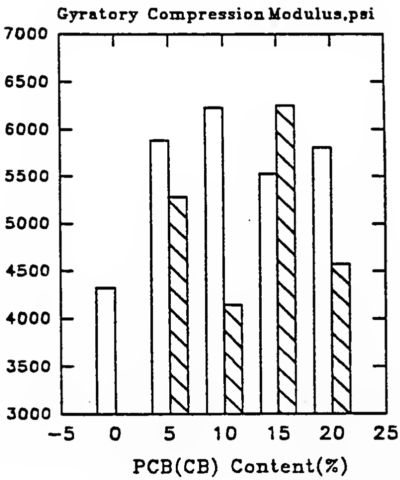


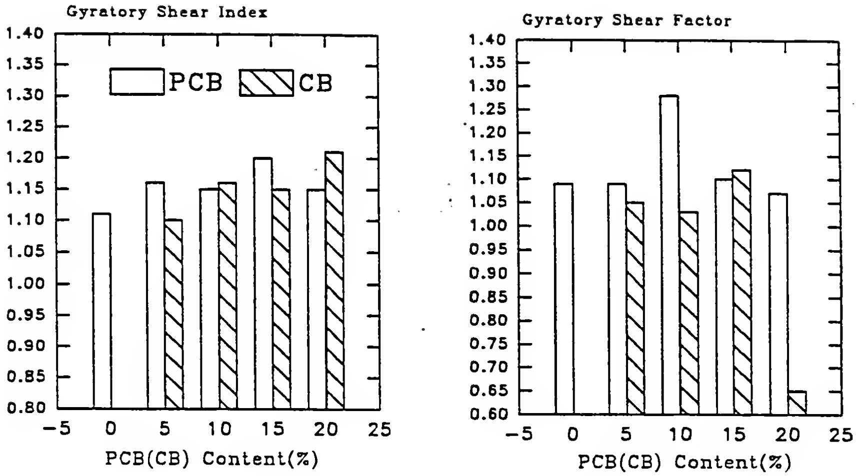




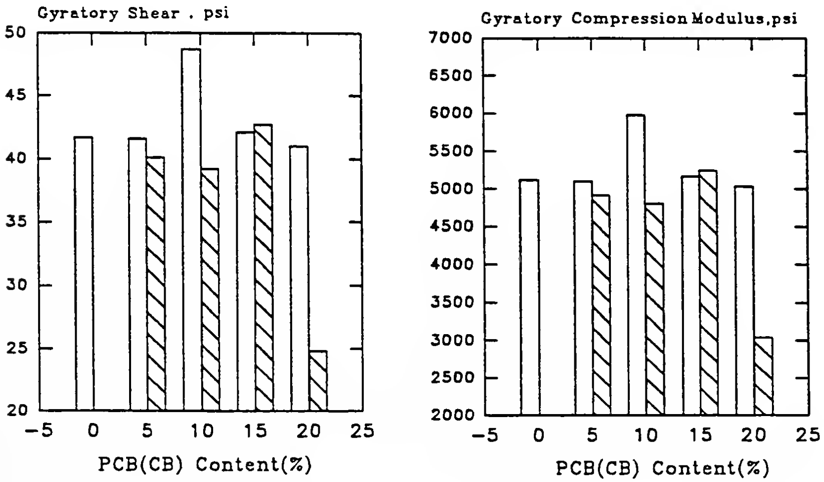
AC-20 Mixture (150 Revolutions)

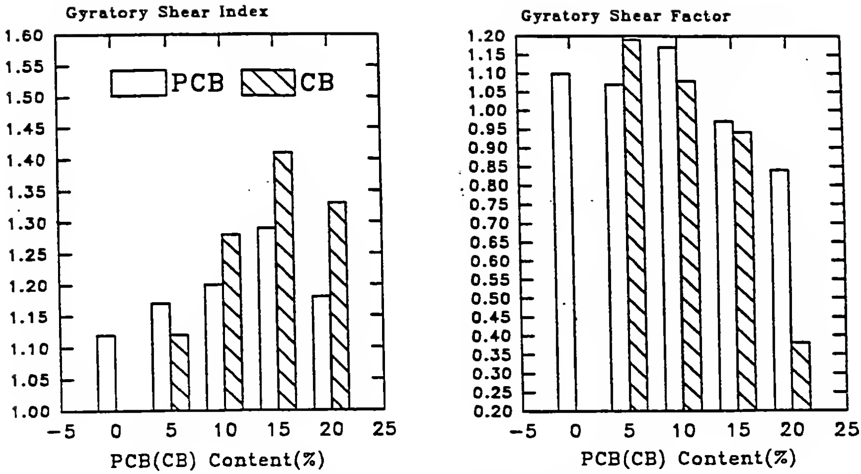




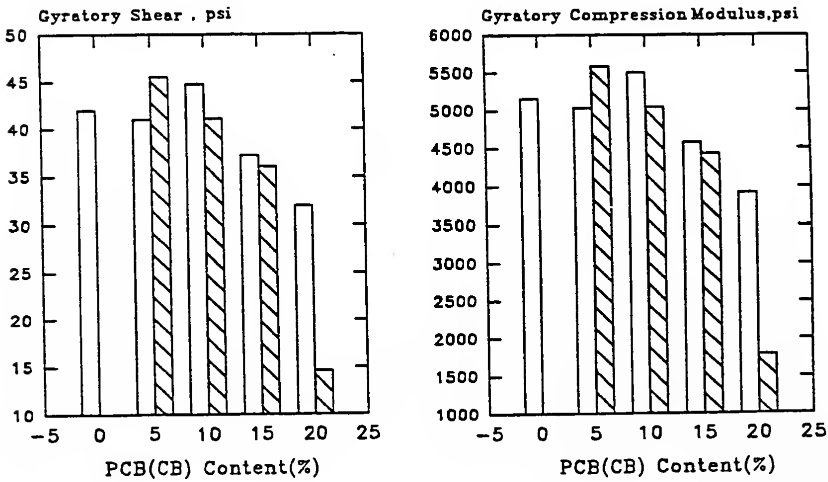


AC-20 Mixture (200 Revolutions)



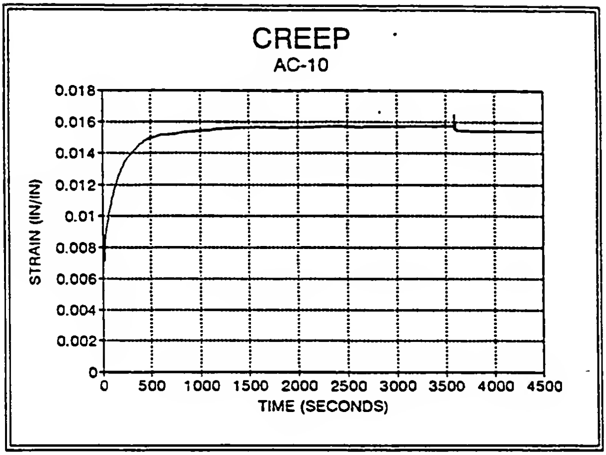


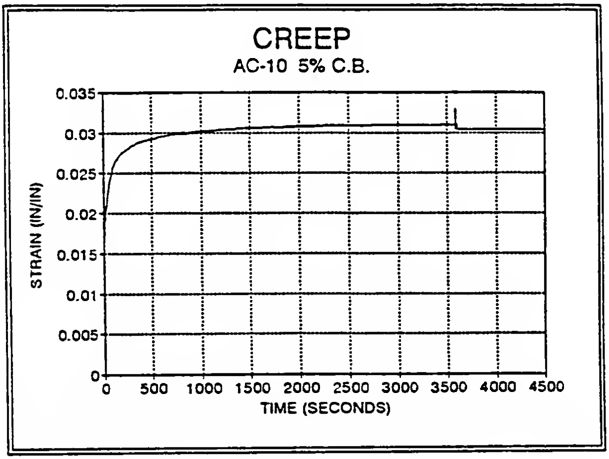
AC-210 Mixture (250 Revolutions)

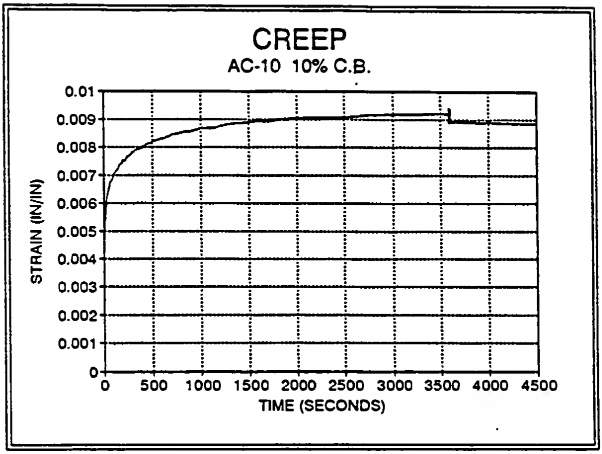


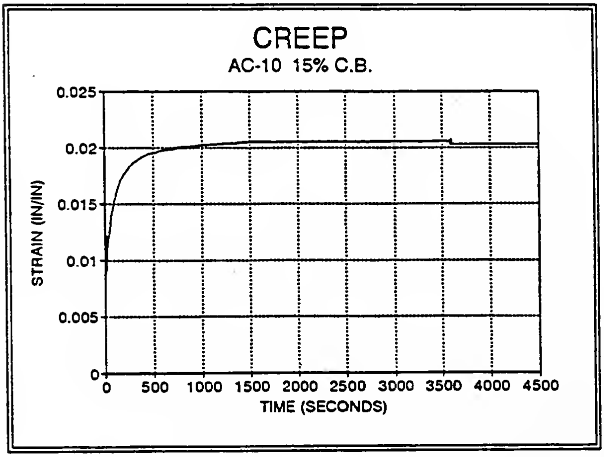
APPENDIX H

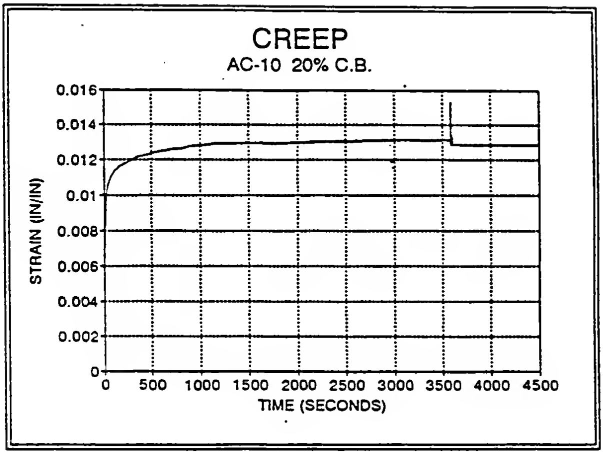
Plots for Creep Test Results

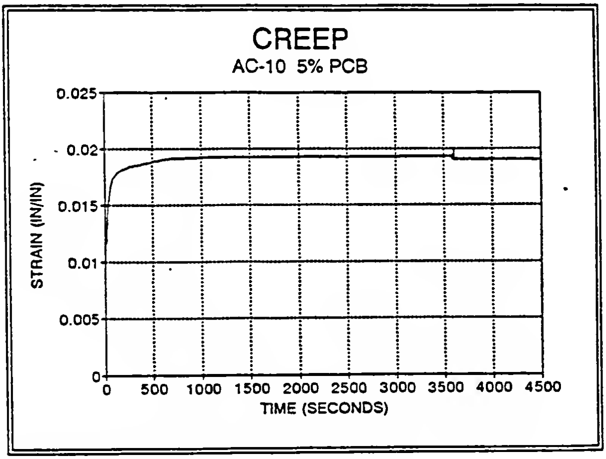

CREEP
AC-10
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

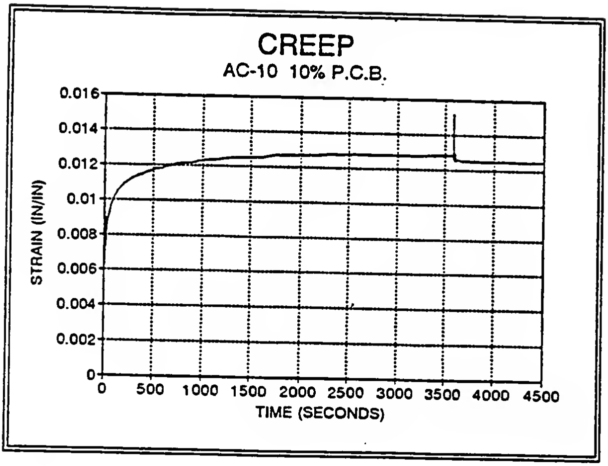

CREEP
AC-10 5% C.B.
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

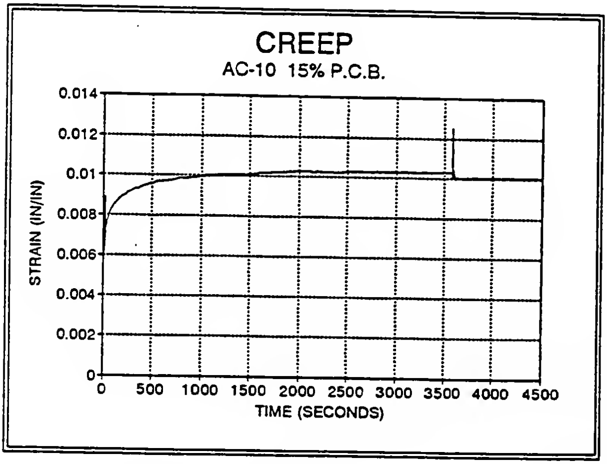

CREEP
AC-10 10% C.B.
STRAIN (IN/IN)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
0 500 1000 1500 2000 2500 3000 3500 4000 4500
TIME (SECONDS)

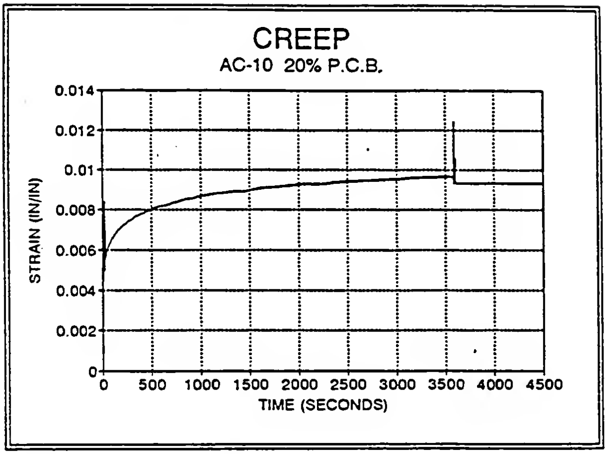

CREEP
AC-10 15% C.B.
STRAIN (IN/IN)
0.025
0.02
0.015
0.01
0.005
0
0 500 1000 1500 2000 2500 3000 3500 4000 4500
TIME (SECONDS)

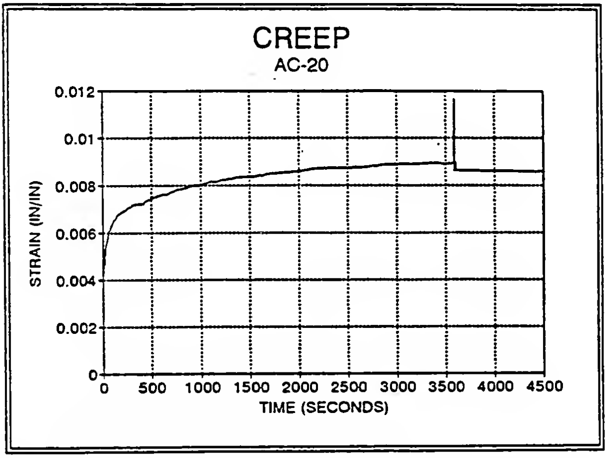

CREEP
AC-10 20% C.B.
STRAIN (IN/IN)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

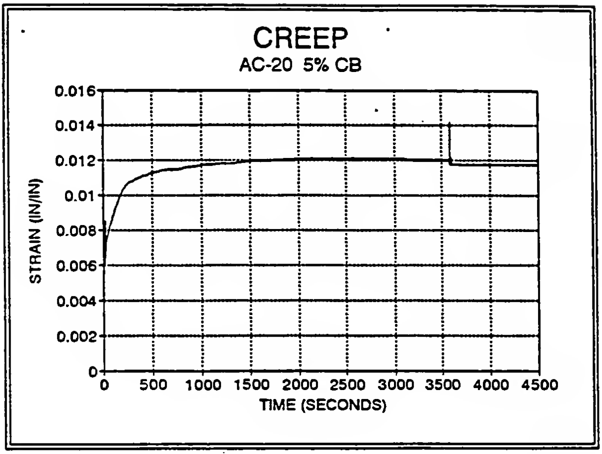

CREEP
AC-10 5% PCB
STRAIN (IN/IN)
0.025
0.02
0.015
0.01
0.005
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

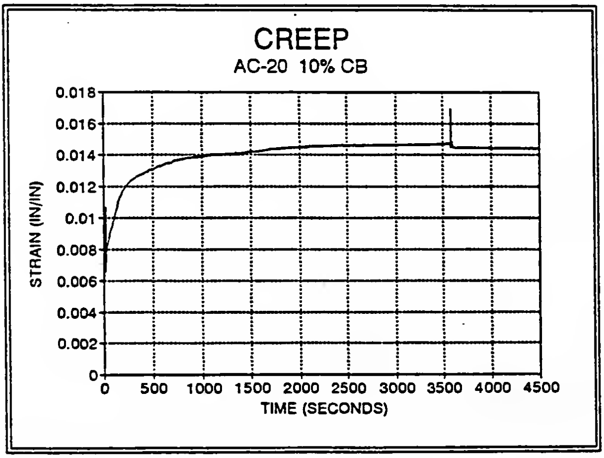

CREEP
AC-10 10% P.C.B.
STRAIN (IN/IN)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

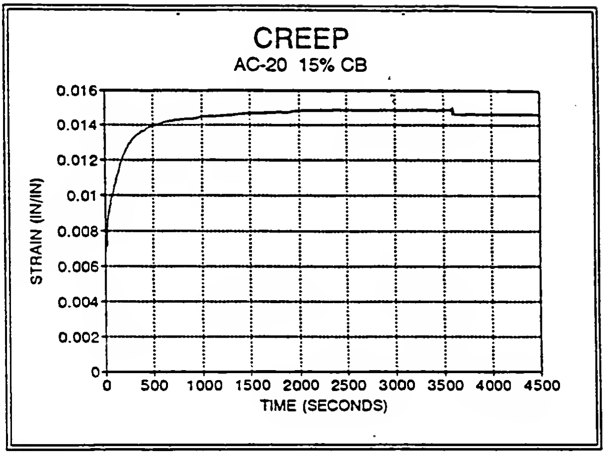

CREEP
AC-10 15% P.C.B.
STRAIN (IN/IN)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

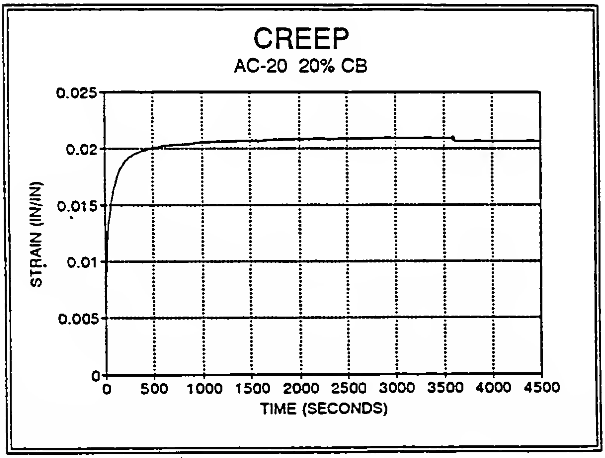

CREEP
AC-10 20% P.C.B.
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

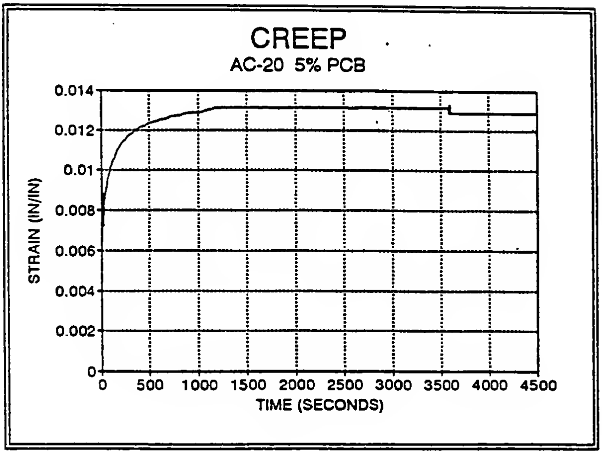

CREEP
AC-20
0.012
0.01
0.008
0.006
0.004
0.002
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

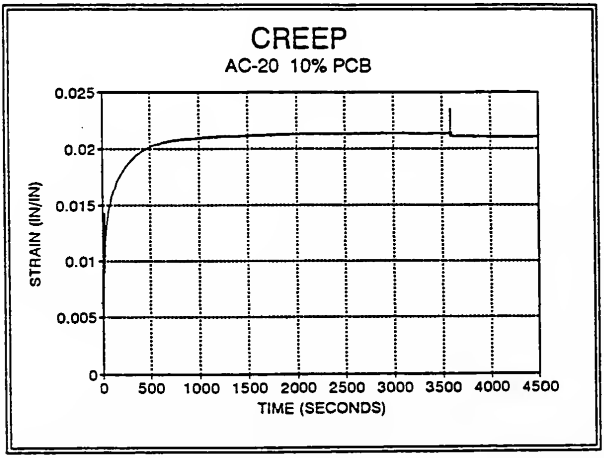

CREEP
AC-20 5% CB
STRAIN (IN/IN)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

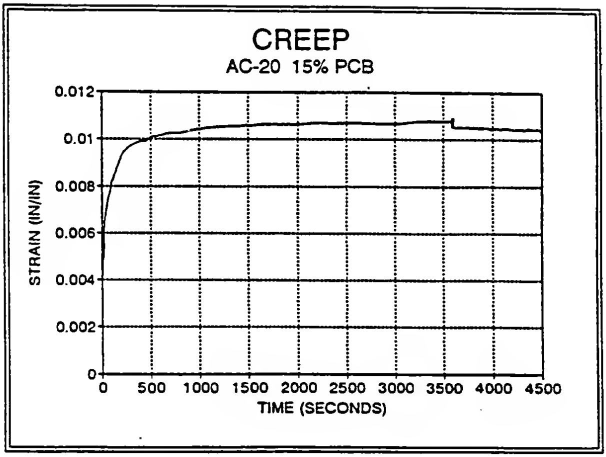

CREEP
AC-20 10% CB
STRAIN (IN/IN)
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

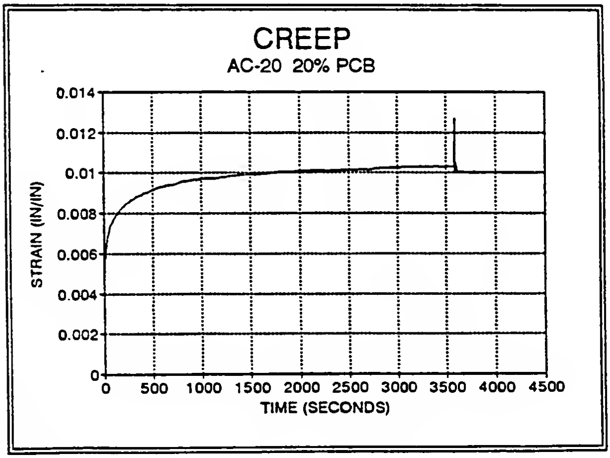

CREEP
AC-20 15% CB
STRAIN (IN/IN)
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)


CREEP
AC-20 20% CB
STRAIN (IN/IN)
0.025
0.02
0.015
0.01
0.005
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)


CREEP
AC-20 5% PCB
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

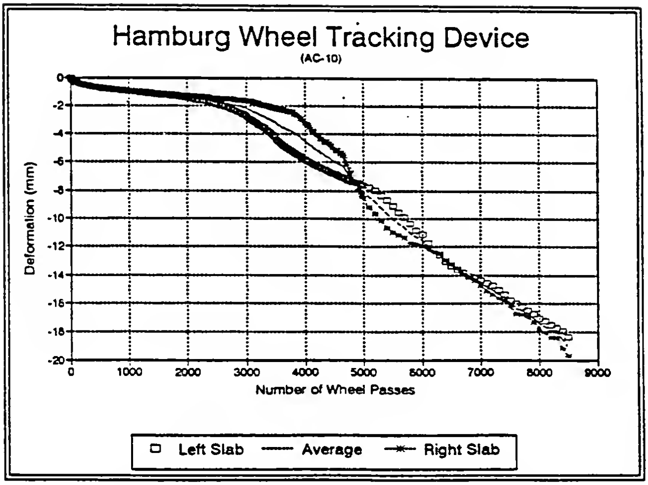

CREEP
AC-20 10% PCB
0.025
0.02
0.015
0.01
0.005
0
STRAIN (IN/IN)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

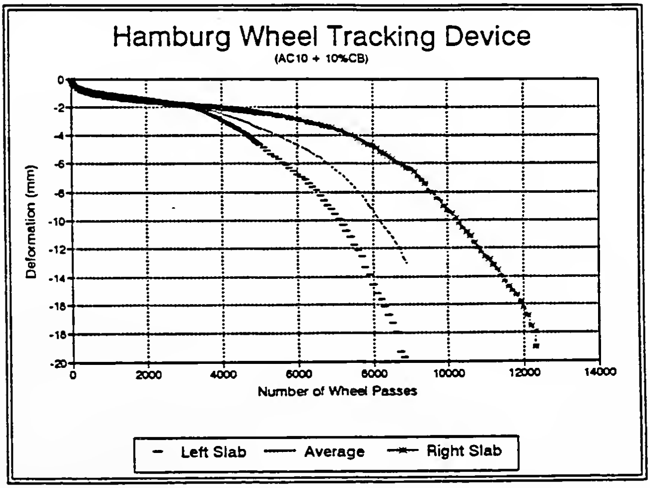

CREEP
AC-20 15% PCB
STRAIN (IN/IN)
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

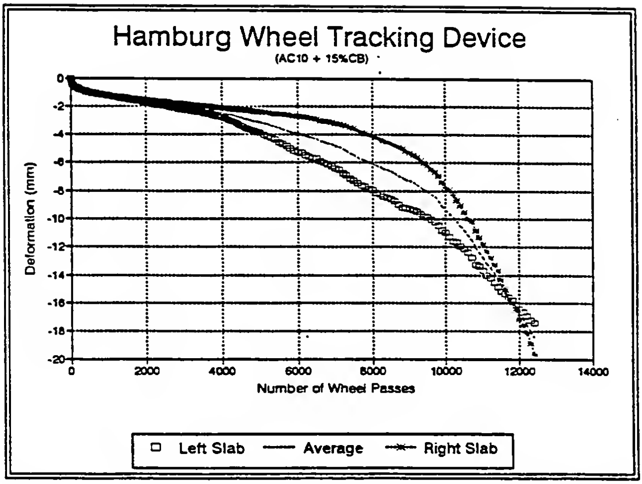

CREEP
AC-20 20% PCB
STRAIN (IN/IN)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
TIME (SECONDS)

APPENDIX I

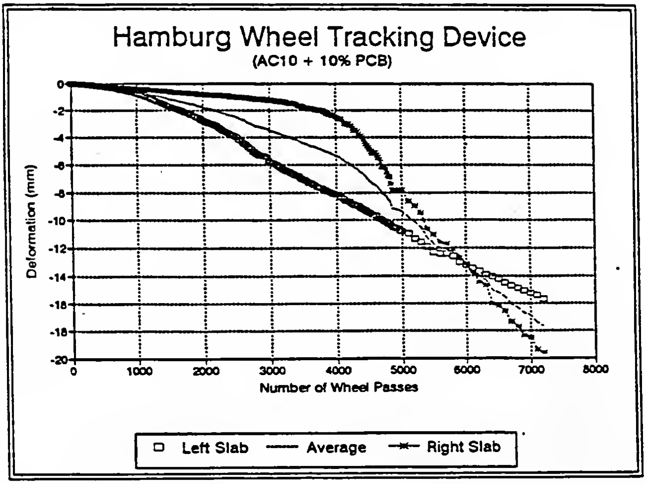
Test Results for Hamburg Wheel Tracking Device


Hamburg Wheel Tracking Device
(AC-10)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
Number of Wheel Passes
Left Slab
Average
Right Slab

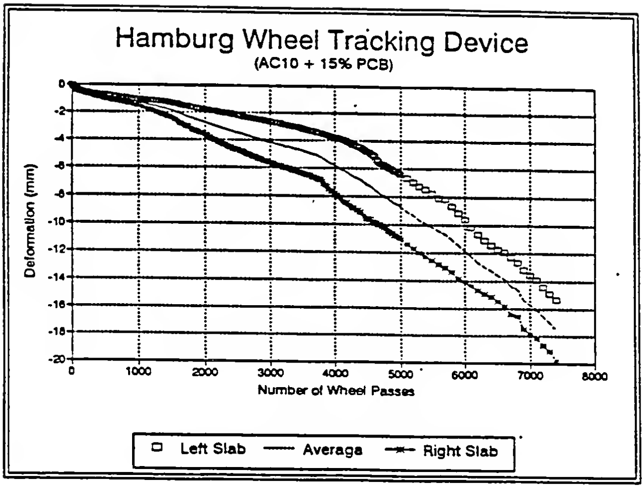

Hamburg Wheel Tracking Device
(AC10 + 10%CB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2000
4000
6000
8000
10000
12000
14000
Number of Wheel Passes
Left Slab
Average
Right Slab

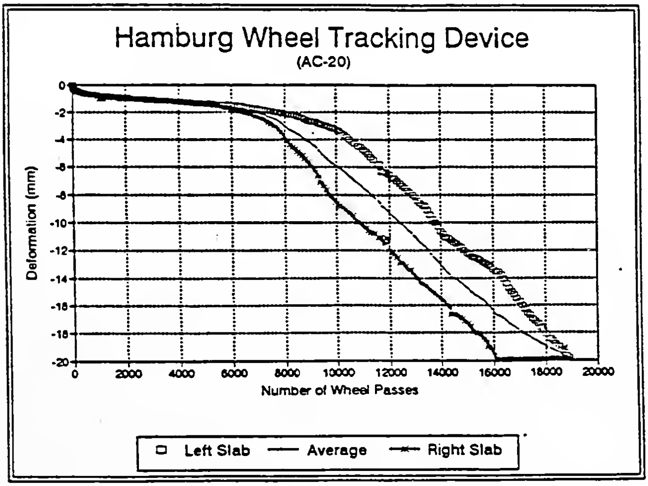


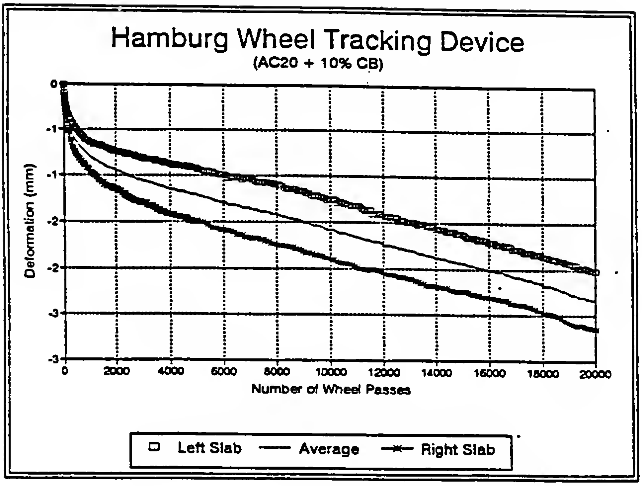
Hamburg Wheel Tracking Device
(AC10 + 15%CB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2000
4000
6000
8000
10000
12000
14000
Number of Wheel Passes
Left Slab
Average
Right Slab

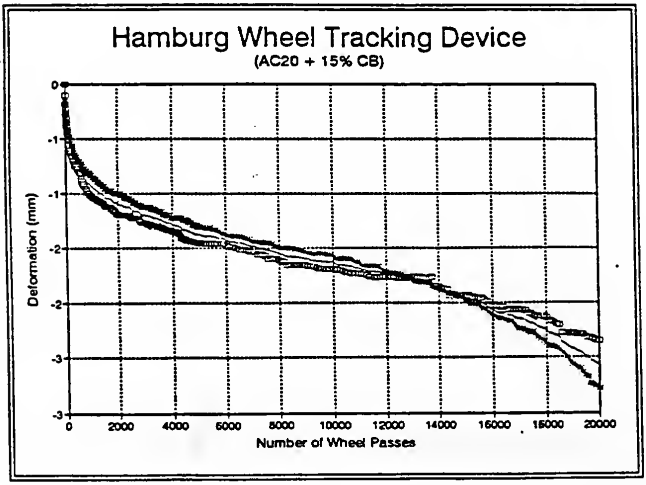


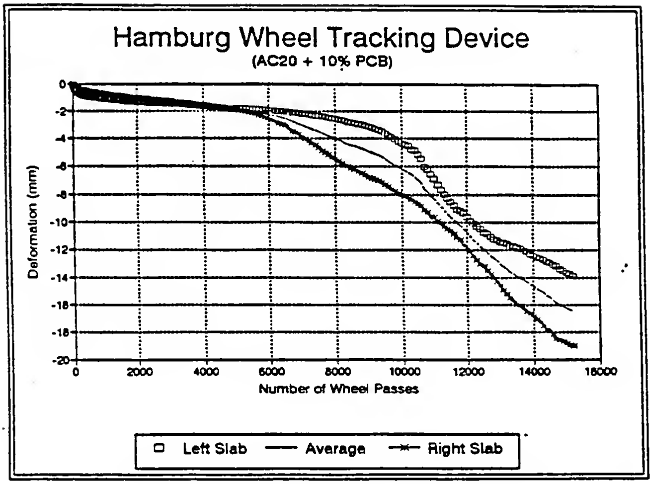
Hamburg Wheel Tracking Device
(AC10 + 10% PCB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
1000
2000
3000
4000
5000
6000
7000
8000
Number of Wheel Passes
Left Slab
Average
Right Slab

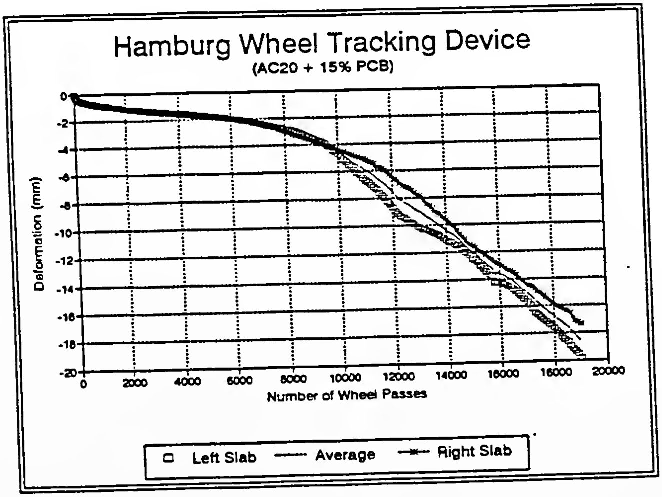

Hamburg Wheel Tracking Device
(AC10 + 15% PCB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
1000
2000
3000
4000
5000
6000
7000
8000
Number of Wheel Passes
Left Slab
Average
Right Slab


Hamburg Wheel Tracking Device
(AC-20)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Number of Wheel Passes
Left Slab
Average
Right Slab


Hamburg Wheel Tracking Device
(AC20 + 10% CB)
Deformation (mm)
0
-1
-1
-2
-2
-3
-3
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Number of Wheel Passes
Left Slab
Average
Right Slab


Hamburg Wheel Tracking Device
(AC20 + 15% CB)
Deformation (mm)
0
-1
-1
-2
-2
-3
-3
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Number of Wheel Passes


Hamburg Wheel Tracking Device
(AC20 + 10% PCB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
Number of Wheel Passes
Left Slab
Average
Right Slab


Hamburg Wheel Tracking Device
(AC20 + 15% PCB)
Deformation (mm)
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Number of Wheel Passes
Left Slab
Average
Right Slab

COVER DESIGN BY ALDO GIORGINI